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STUDIES OF

MUIR GLACIER, ALASKA

HARRY FIELDING REID

WASHINGTON

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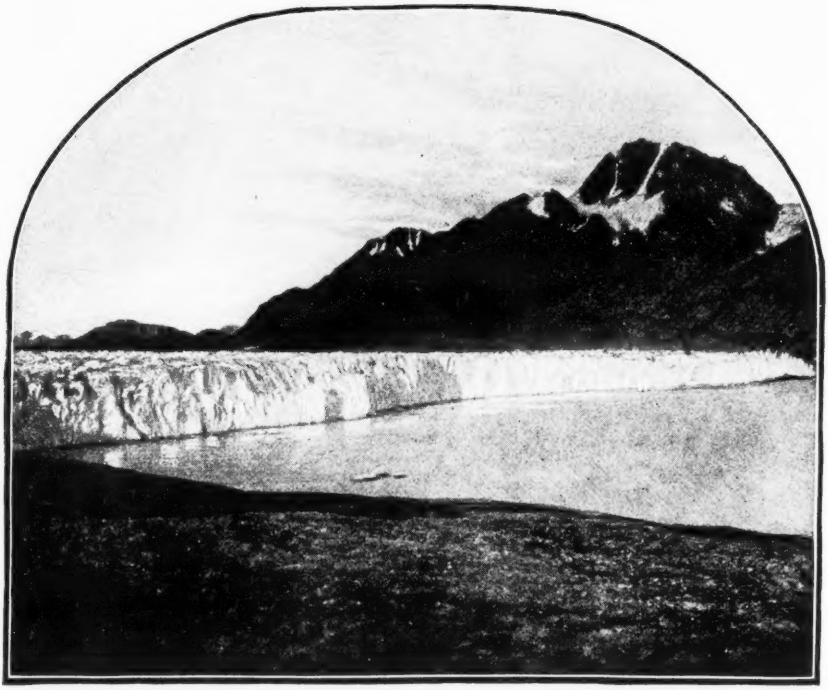

FRONT OF MUIR GLACIER AND MOUNT CASE, LOOKING EASTWARD.

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STUDIES OF MUIR GLACIER, ALASKA.

BY HARRY FIELDING REID.

(*Accepted for publication December 11, 1891.*)

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Introduction and Narrative.

A desire to see the Alaskan coast more thoroughly than is possible to ordinary tourists led to the formation of a party to spend the summer of 1890 encamped there.

The description of Muir glacier by Professor Wright* turned our attention to that point. Its accessibility and the interest

* The Ice Age in North America, 1889, chap. iii.

awakened by its reported motion of 70 feet a day decided us to camp at its mouth and study the glacier and its neighborhood as thoroughly as time would permit. The first requisite was a reliable map of the region. None such existed, and we determined to devote much time to a survey and to make a map which would show with some accuracy the extent and form of the glacier and the positions of the mountains which surmount it, and also serve to determine what changes may take place in the future. We also planned a careful measure of the motion of the ice, a determination of the magnetic elements, a regular meteorologic record, a study of the geology of the region, a collection of plants, and observations of all indications of change in the extent of the glacier, the amount of glacial erosion, etc.

The party consisted of Mr H. P. Cushing, who took charge of the meteorologic records, the geologic observations, and the collection of plants; Messrs H. McBride, R. L. Casement, J. F. Morse, C. A. Adams, and the writer. It gives me pleasure to acknowledge that it would have been impossible to accomplish the work if it had not been for the cheerful and efficient aid which all my companions rendered.

Muir glacier seems to have been known only to the Indians until 1879, when it was visited by Professor John Muir and Reverend Mr Young; but they were prevented by bad weather from much exploration. In 1886 Professor G. F. Wright devoted a month to its study. We are indebted to him for a very interesting description. Until our visit, in 1890, these were the only attempts to obtain any accurate knowledge of the glacier. Glacier bay offers the luxury of exploration. Visited weekly during the summer by the steamers of the Pacific Coast Steamship company, the explorer can take with him everything necessary to his comfort, can renew supplies when necessary, can receive and despatch his mail, and still be in a region of which little is known—a region of great interest to the geologist and student of physical geography. It seems strange that it is not more thoroughly studied.

On July 1st the *George W. Elder* cast anchor in Muir inlet, not far from the glacier, and landed our instruments, tents, personal baggage, and provisions on the eastern shore. We found Professor Muir and Mr Loomis encamped there. They had come also to study the glacier, and added much to the pleasure of our stay. We immediately set to work to put up our tents, and

before evening everything was in good shape. We brought boards from Juneau for flooring, tables, etc, which added materially to our comfort and convenience. A book-shelf held our small library of works on glaciers, logarithmetic tables, etc. A gasoline stove enabled us to cook our meals with ease, and camp-stools permitted us to eat them in comfort. This was to be our base-camp, and, in honor of Professor Muir, we named it *camp Muir*. Here we stayed until the middle of September, making various excursions of several days' duration to points too distant to be visited in one day, always, however, leaving two of our party at camp to make the meteorologic observations. We had with us a row-boat 16 feet long, provided with a sail, and during our stay we bought from the Indians a small dugout canoe which would carry three persons.

On one occasion, in company with Professor Muir, we rounded the western headland of Muir inlet and pushed a mile or two up Glacier bay. The water was so full of floating ice, in pieces large and small, that our progress was very slow, and we finally landed for the night, hoping to find clearer water the next day. In this we were disappointed, and therefore rowed back again and crossed the bay to the large island opposite Muir inlet. It was in this limestone island that Mr Cushing found the fossils which make it probable that these rocks are of Paleozoic age. Later in the evening we returned to camp Muir. On another occasion, following Professor Muir's example, we made sleds on which we packed our blankets, provisions, and instruments, and spent five days exploring and mapping the eastern part of the glacier. We ascended Tree mountain (2,700 feet) and Snow dome (3,300 feet), which, though of moderate elevation, command excellent views. Another time we visited the stations marked *S* and *T* on the accompanying map (plate 14), and ascended one of the peaks just to the westward. We also ascended Pyramid peak, approaching it by the valley of the Dying glacier. The weather unfortunately was misty, so that we added little to our knowledge of the mountains toward the west, except to see that they were numerous and did not seem to surround any very large valleys like that occupied by Muir glacier.

Shorter excursions were made on all clear days to points more easily accessible. Among these the most interesting were connected with the measure of the motion of the ice. To plant our flags where we wanted them required us to make a way among

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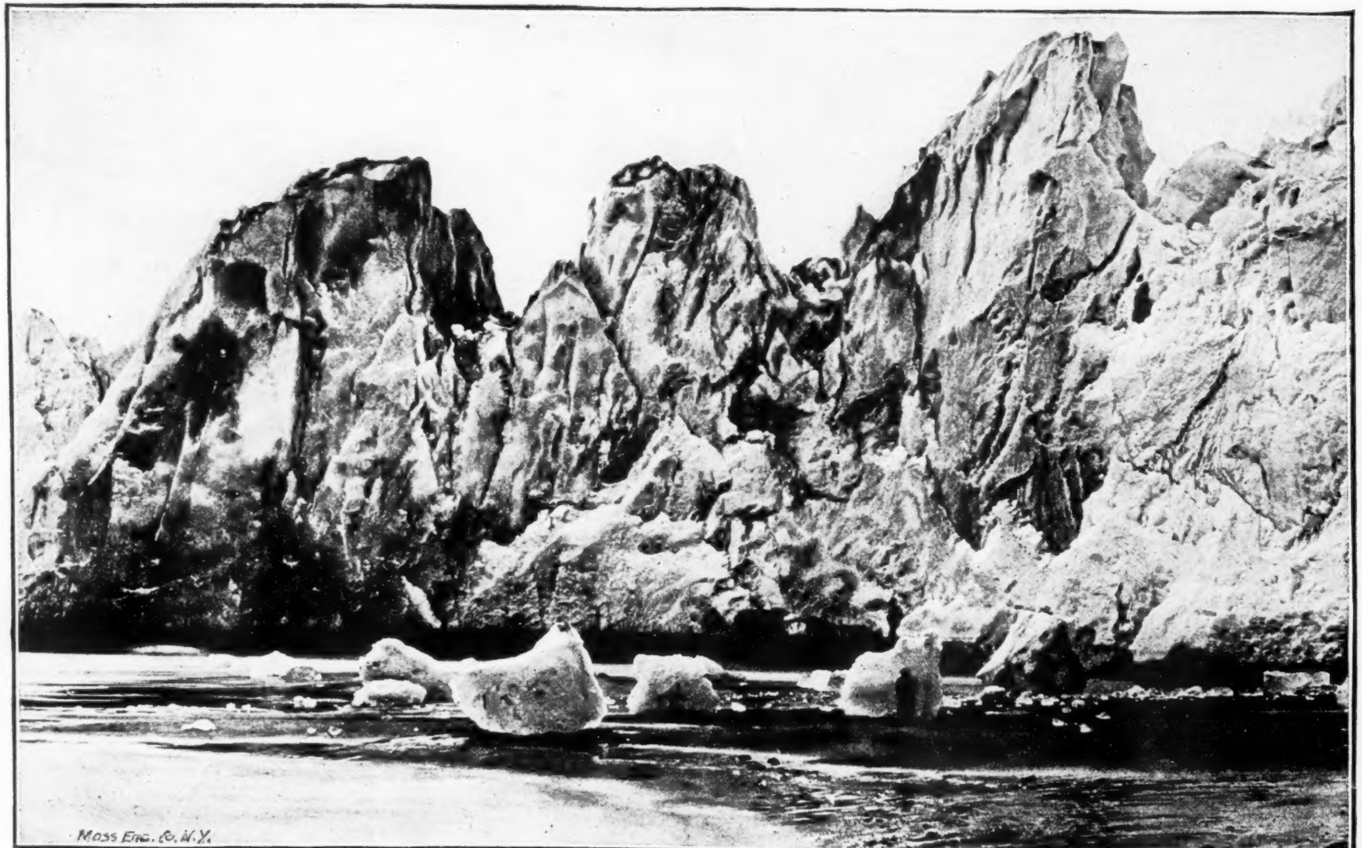

ICE PINNACLES AT END OF MUIR GLACIER.

the crevasses, which offered great difficulties. Some experience in the Alps had taught me what means were necessary for progress in such places and what precautions should be taken to avoid accidents. We were always roped together, and were provided with ice-axes which served to cut steps in places where we could not otherwise stand. Balancing on narrow ridges, creeping along steep walls, or crossing crevasses on pieces of ice that had fallen in and bridged them over, were the usual methods of progress. Our precautions, however, rendered accident impossible.

When at Pyramid harbor, in Lynn canal, we engaged William York to go with us to help in camp-work. At the end of the first month, finding the work too confining for him, he left us with our consent and made his way back to Pyramid harbor, following the stream down Main valley to Lynn canal. After his departure we did all the camp-work ourselves.

The officers of the steamships were very courteous to us. Captain Carroll brought us all the material, ready cut, to make a house with two windows and a door. It was put up during a rainy spell, when we could not do any work away from camp. Indians, or as they are called in this region "Siwashes," had sealing camps in Glacier bay, but only visited the inlet when the steamers brought tourists, with whom they carried on a lively trade.

General Geography.

The southeastern extremity of Alaska consists almost entirely of an archipelago, which occupies a space nearly three hundred and fifty miles long and a hundred miles wide. The islands, large and small, are closely packed together, and the waterways between them are deep and narrow, and often form long straight canals. The islands are mountainous and precipitous, affording few landing places. Their slopes are densely wooded, mostly with spruce. The rough surveys of Vancouver a hundred years ago, as revised later by Tebenkof and others, were until 1867 largely relied on as supplying the most accurate information of parts of the coast. Since that year the explorations and surveys made by the United States Coast and Geodetic survey under the direction of Assistant Davidson, acting Assistant Dall, and, during the period from 1881 to the present time, by naval officers of the navy attached to the same survey, have resulted in the

publications of charts and other data making known the more important channels and waterways with ample accuracy for navigation.

Southeast of the Alaska-British Columbia boundary the islands become larger and the waterways wider. Cross sound and Icy strait form the northwestern boundary of the archipelago. From them two deep inlets, Lynn canal and Glacier bay, stretch toward the north and northwest, forming, with the Pacific ocean, two peninsulas. The great Fairweather group of mountains occupies the western part of the peninsula between Glacier bay and the Pacific. The eastern part is occupied by another and much lower range, whose peaks rise about 5,000 or 6,000 feet above the sea. Their northeastern slopes are gradual and are covered with large glaciers, some of which reach tide-water and discharge icebergs into Glacier bay. Between these two ranges there seems to be a deep valley, which drains the eastern slopes of the Fairweather group. This is probably filled by a long narrow glacier discharging into Taylor or Dundas bay. Little was known of the peninsula between Glacier bay and Lynn canal before our expedition mapped its northern part, except that it is entirely made up of glacier-bearing mountains, whose peaks are from 5,000 to 7,000 feet high.

Northwest of Cross sound the character of the coast changes abruptly; the coast line becomes continuous, without outlying islands, and broken by few inlets; and mountains of great height rise immediately from the water's edge. We can, therefore, topographically divide the southeastern coast of Alaska into two regions. The line between them passes along Cross sound; then follows the valley just northeast of the Fairweather range for 40 or 50 miles, beyond which point we know nothing whatever about it. This topographic difference seems to be accompanied by a geologic difference. Mr Russell has shown that the St. Elias alps are of Tertiary origin;* and probably the Fairweather group belongs to the same range, though I believe it has not been explored. If this is true, the Fairweather mountains are of Tertiary origin, while the rocks forming the mountains about Muir glacier, and probably the rest of the same topographic region toward the southeast, belong to the Paleozoic and Archean.† Another difference is quite marked. Mr Russell has found raised

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* Nat. Geog. Mag., vol. iii, 1891, p. 172.

† See Supplements I and II.

MOUNT WRIGHT AND UPPER PART OF DIRT GLACIER, FROM SHOULDER OF MOUNT CASE.

beaches about Yakutat bay,* indicating that the land there has risen, whereas the submerged trees in Muir inlet show that this region is sinking. These striking facts seem to show that the valley between the Fairweather mountains and Glacier bay follows the line of an immense fault, which brings Tertiary and Paleozoic rocks into close juxtaposition. It is most unfortunate that we have no observations on the Fairweather mountains that will enable us to confirm or correct this interesting indication.

Glacier Bay and Muir Inlet.

Glacier bay itself has not been surveyed; the delineation in the coast survey charts is correct only in its general outline. It trends northwest and southeast, and is about forty miles long by ten wide. There are a great many islands in the bay. The Beardslee islands, which fill the eastern side for a distance of about twenty miles from its mouth, are made up, at any rate in part, of modified glacial till, and are generally thickly wooded, as are also the shores in the lower part of the bay. The channels between these islands are narrow, and often give one the impression of waterways cut through the land. The islands in the upper part of the bay are quite different; they are of solid rock, and are scored, polished, and rounded by glacial action. They occur singly, are usually elongated, and have the longer axis parallel to the nearest shore. They, like the mainland, descend abruptly into the water, and only at long intervals can even a small beach be found. In this part there are no trees. Several glaciers force their way down to the water level and discharge bergs into the bay; most of them end in narrow inlets two or three miles back from the bay proper. Muir glacier is of this type; its inlet, which runs nearly north and south, has its southwestern terminus on Glacier bay about five miles from the end of the glacier; the eastern shore line rounds gradually into the bay without well marked headlands. The inlet gradually narrows as we approach the glacier, being about one and a half miles wide at its upper end. On each side are deposits of roughly stratified sands and gravels, covered with a thin layer of moraine débris. On the western side these deposits form a comparatively level plateau from 150 to 200 feet high, which extends about four miles south of the present ending of the gla-

* Op. cit., p. 82.

cier, and is about a mile wide. Its surface bears a number of shallow lakes; and here and there deep ravines mark the positions of former watercourses. The western subglacial stream has cut a gorge through this plateau, and exposed the buried forest described by Professor Wright (see page 39). For three-quarters of its length, the plateau ends on the water side in precipitous bluffs, below which there is a narrow beach, only covered by the highest tides. On the eastern side the bluffs only extend for a half mile or so; the upper surface of the deposit is not a plateau, but slopes gradually down to the bed of the glacial stream at the foot of the mountains. This stream empties into the inlet just below where the bluffs end. South of the stream the deposits slope gradually up from the beach to a height of about 400 feet against the mountain side.*

The inlet is quite deep. Professor Wright reports a sounding by Captain Hunter of 516 feet about 1,300 yards south of the present position of the ice front. Captain Carroll last summer (1890) found within a hundred yards of the ice-front a depth of 720 feet. This does not necessarily indicate that the inlet increases in depth as we approach the immediate neighborhood of the ice, for the earlier sounding may not have been taken in the deepest part of the channel.

Muir Glacier.

General Features.

Muir glacier occupies a depression in the mountains about 35 miles long and from 6 to 10 wide. It is fed by a great number of tributaries, of which the first northern, the second northern, and the northwestern are by far the largest. These again are made up of many smaller glaciers. The general slope of the surface, based on a barometric reading made between Tree mountain and Granite canyon, is about 1° 15′. The appearance of the glacier toward the northwest indicates that the slope there is about the same. The total area drained by this system is about 800 square miles; the actual surface of the ice being about 350 square miles. The area draining into Muir inlet is about

* For an excellent description of these deposits see "Notes on the Muir glacier region" by Mr H. P. Cushing in Am. Geol., vol. viii, 1891, pp. 207–230, pl. iii, and map; c. f. ibid., vol. ix, 1892, pp. 190–197.

WHITE GLACIER.

700 square miles. Most of the precipitation which falls on this area flows off as water in the subglacial streams; the rest, compressed into ice, is forced through the narrow gateway 2½ miles wide into the inlet, where the glacier terminates in a vertical wall of ice varying from 130 to 210 feet above the water surface, from which large masses are continually separating to become icebergs (see page 48 and plates 1, 2 and 13). As already stated, the depth of the water is in places 720 feet; and as this is not enough to float a mass of ice rising so high above the water as Muir glacier, the ice must reach to the very bottom and must attain a thickness of 900 feet. The actual length of the ice-front facing the water is 9,200 feet, or 1¾ miles.

On each side the glacier sends forward a wing, which rises in the shape of a wedge over the stratified sands and gravels of the shore.* The upper surfaces of the wings, like the ice-front, are about 200 feet above the water level. This applies only to the parts of the wings overlooking the inlet; the parts nearer the side mountains are 50 to 100 feet lower; and here the ice ends like an ordinary alpine glacier. The wings are fringed by treacherous quicksands, which support large stones and look firm enough; but the tourist who steps upon them carelessly will quickly sink in over his ankles. These quicksands are composed of fine glacial mud, thoroughly soaked with water from the melting ice.

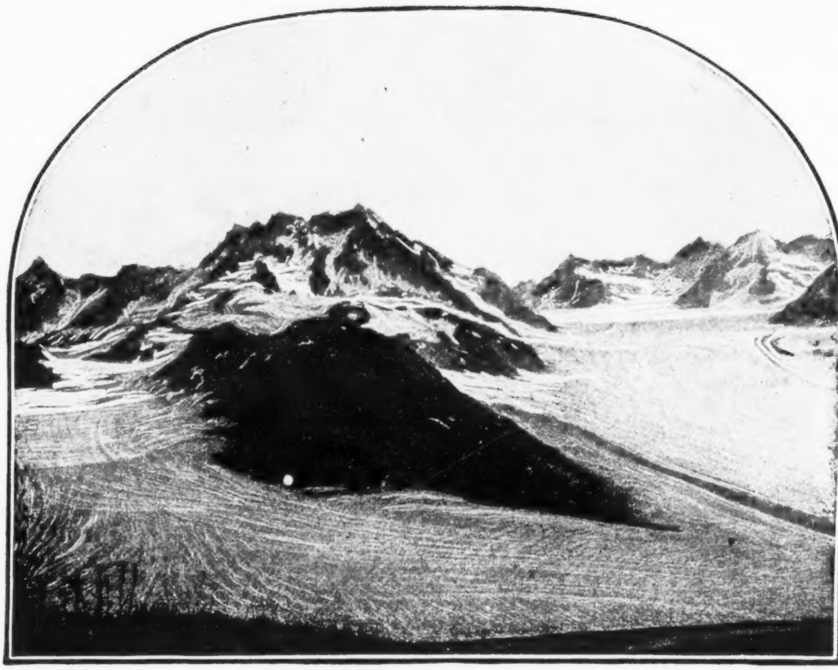
The ice-front has a wonderful coloring. Places from which ice has recently broken off are deep blue, sometimes almost black. This color lightens under exposure to the air and sun, and in a few days becomes pure white. All stages are represented in the ice-front, which therefore shows all shades of blue in striking variety. The blue color of the ice is caused by the absorption of the other constituents of the light passing through it, and is exactly analogous to the hues of colored glasses. When exposed to the sun and rain the ice undergoes a kind of weathering near its surface, which prevents the blue light within from passing out and reflects nearly all of the light which falls on it from outside; so that we then see merely ordinary white light reflected, practically unchanged, from the ice.

* Mr Cushing has published (op. cit., pl. iii) a reproduction of a photograph showing the glacier riding on the these gravels.

Tributaries.

Beginning at the right, we find three tributaries coming in from the southeast. The Dirt glacier (see plate 3) sweeps around in a great curve from behind mount Wright; its lower part is completely covered with débris for fully a mile and a half from its mouth; above this the glacier is particularly clean. The White glacier (see plate 4), which joins the Muir just beyond mount Case, is remarkably beautiful. Arising in a circle of snowy mountains it flows down a deep narrow valley at an angle of about 10°, its perfectly white surface marked by the wonderfully symmetrical parallel curves of three or four dark moraines. It is about four miles long and half a mile wide. A little further is the southeastern tributary (see plate 5), fed by a number of smaller glaciers. This glacier is not hemmed in by mountains but crosses a divide east of a_{15}, over which the ice flows into some valley on the other side. This divide has an altitude of 2,000 or 2,500 feet. About ten miles southeast of our camp a large glacial stream discharges into Glacier bay. It must drain the southern side of the mountains which bound these three tributaries.

Still further eastward is Main valley, which, though it probably once contained a tributary, is now an outlet of Muir glacier. The ice flows down this valley in a stream three miles wide, apparently with a very slow motion. A few miles down the valley the ice ends in a high wall facing Main lake, into which it occasionally discharges a berg. The stream draining this lake flows through a broad flat valley of sands and gravels toward the southeast, and finally empties into Lynn canal. The three valleys entering the eastern side of Main valley also have flat gravel-covered floors, through which rush the streams from the snow fields and small glaciers at their heads. Two of these valleys are beyond the present termination of the glacier. Formerly the ice must have extended across their mouths, hemming them in and converting them into lake beds. The upper valley is now in just this condition. The lake which occupies it has been called Berg lake on account of the great number of icebergs in it last summer (1890). Just north of the entrance to Main valley lies Girdled glacier, so called on account of the moraine which completely surrounds it (see plates 6 and 11). It can be seen from the end of Muir glacier, but is so foreshortened that one



THE SOUTHEASTERN TRIBUTARY, FROM TREE MOUNTAIN.

would not suspect that the visible portion is 3½ miles long. West of and separated from Girdled glacier only by a narrow ridge is Granite canyon, a deep gorge with precipitous sides, running about eight miles into the heart of the mountains.* The ice slopes downward into the canyon, whose drainage, however, must be back under the ice; for although I was unable to see every point of the ridge which closes in the further side of this valley, I could see sufficient of it from different points of observation to convince me that no part of it is less than a thousand feet above the floor of the valley. This curious condition seems to be due to the fact that the valley once contained a tributary glacier, which on account of the present smaller supply of ice and the reflection of the heat from the northern side of the canyon has melted down more rapidly than the surface of the main glacier, so that now (although this I could not see) the glaciers draining into this valley are probably entirely separated from the ice entering at its mouth. The tributaries so far mentioned supply none of the ice which forms the ice-front in Muir inlet; all the ice coming from them that does reach the end of the glacier is compressed into about 800 yards between the ice-front and the mountain on the east. If a line were drawn from the nunatak *H* to the eastern side of the first northern tributary and a second line toward the northwest at right angles to the first, the sources of all the ice which reaches the ice-front would lie in the quadrant between them.

The first and second northern tributaries and the main glacier present no striking peculiarities (see plate 7). These are immense streams of ice, fed by innumerable small glaciers. The mountains which rise between them and through them are deeply laden with snow, and toward the northwest seem to raise only their summits through the icy sea. The extremities of these branches could not be clearly determined, although they all seem to connect by low divides with valleys beyond. The northwestern tributary heads in two beautiful white conical mountains, which we called the Snow cones. A part of its ice flows over the divide between l_3 and l_5, and joins a large glacier which is probably identical with the one entering the head of Glacier bay. The western tributary supplies no ice to the ice-front; moreover,

* This was named from the crystalline nature of the rock, which, however, according to Professor Williams' report (supplement ii), is not a true granite.

its snow fields are too small and too low to supply ice for a glacier of its width, and it is evidently melting away. At its western extremity it crosses over a divide and flows into a valley beyond.

The mountains immediately surrounding Muir glacier are not high, the highest peaks being between 5,000 and 7,000 feet. The mountains which first attract the attention of the visitor are mount Wright,* mount Case,† and Pyramid peak (see plates 1, 3 and 8)—the first two by their jagged crests, seamed by snow corloirs; the last by its symmetrical form; all three by their proximity. The more distant mountains seem to lack somewhat in individuality. This is largely due to their distance, for they are from fifteen to thirty miles away. All is bare and bleak, and the scenery is entirely lacking in picturesqueness. If we go out on the ice as far as *H* the three bold peaks of mount Young show themselves over Tree mountain (see plate 9), and the beautiful Snow cones at the head of the northwestern tributary can be seen.

Surface of the Glacier.

The surface of the ice presents the honeycombed appearance common to all glaciers; it crunches under the foot, making walking very tiresome, and rapidly wears out one's boots. This surface ice varied very much with the weather. Sometimes after rain the ice was hard, smooth, and blue; sometimes the rain increased the roughness.

Crevasses.

The eastern part of the glacier was free from all large crevasses; none in this part were too large to be stepped over. This, of course, indicates a small differential motion, not necessarily a small actual motion. That this, however, is also small follows from our measures, which show that although all the ice supply from the eastern part of the glacier is crowded through a narrow space between the ice-front and the mountain to the east, still the greatest motion here is only about two inches a day (see page 45). The amount of crevassing in the other parts of the

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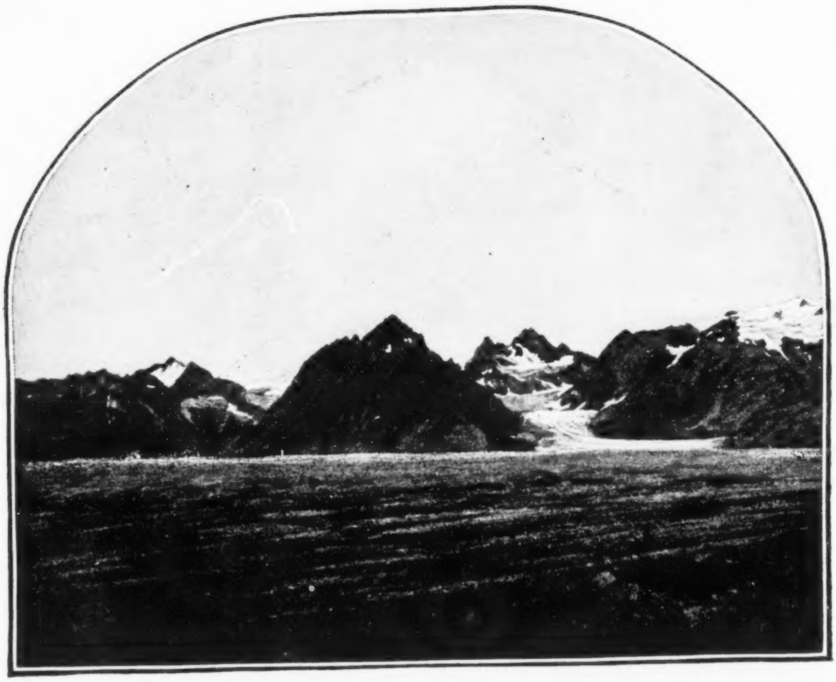
* Named after Professor G. Frederick Wright, who spent some time studying Muir glacier in 1886. He has described it in his Ice Age in North America, chap. iii.

† Named after the Case School of Applied Science, Cleveland, Ohio.



GIRDLED GLACIER, FROM P.

glacier varies much with the locality. From an elevated point such as *V*, from which the minor irregularities are not prominent, the general smoothness seems broken over limited areas, like the surface of a still lake ruffled in places by puffs of wind. These are, of course, where the bed of the glacier presents some irregularity. Below them the sides of the crevasses are again pressed together, and the surface resumes its general smoothness. The increase in the width of crevasses during the summer was very noticeable. In the beginning of September we were unable to cross the northwestern tributary, although earlier in the season Professor Muir crossed it without much difficulty.

The place where the crevasses were most marked was the immediate neighborhood of the glacier's mouth. Here two sets of crevasses cutting each other obliquely divided the ice into great lozenge-shaped masses, which, under the influence of the sun, rain and winds, melted, in some cases into narrow ridges, in others into sharp pinnacles. The ice, white near the surface, becomes bluer and bluer as one looks deeper into a crevasse, which finally ends in a dark narrow crack. This gives the impression of immense depth, but I do not believe that any of these crevasses are much over 150 feet deep. We sounded one and found it 123 feet. The best evidence, however, lies in the sections of the crevasses shown in the photograph of the ice-front from which plate 13 is reproduced, in which the crevasses do not extend to the water level, which in this part of the ice-front is less than 200 feet below the surface of the ice. The ribbon structure of Forbes was everywhere visible. On many of the pinnacles it could be seen cutting the stratification at a high angle.

Melting and Drainage.

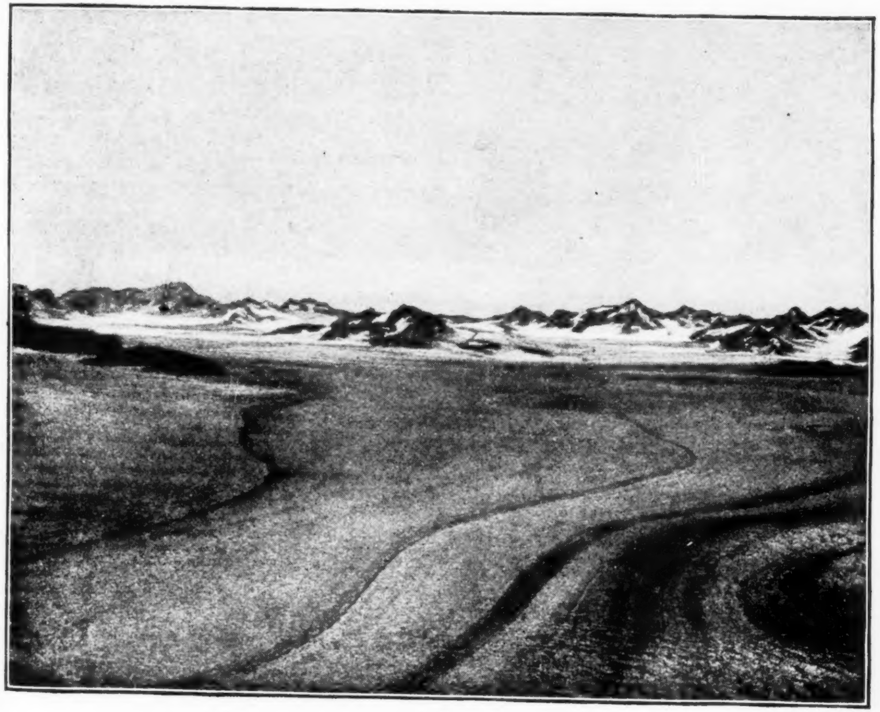
The stakes put in the ice to measure the motion of the eastern part rose about 14 inches in 7 days, which indicates a melting of about 2 inches a day. This method is not reliable, and we can consider the result as only approximate. In this particular portion of the glacier the ice is very friable, and the water does not collect on the surface in pools and streams, but sinks through the ice and is carried off by some crevasse. The portions just west of *G* and between White glacier and *I* contain many surface streams which pour into crevasses or moulins; but none of these streams were two large to leap, and all of them were perfectly clear.

After falling into a crevasse the water sometimes reaches the bed of the glacier and sometimes flows along a channel in the ice. We saw a very good example of such a channel. When we first came to the glacier, early in July, there was a large opening like a sewer in the face of the ice-front near the eastern shore, some fifty or a hundred feet above tide-water, from which issued a strong stream of very muddy water. The opening must have been 200 square feet in cross-section, of which one-half was occupied by the stream. Now, muddiness is a characteristic of water which has flowed along the bed of a glacier, clearness of the surface water; I therefore infer that this stream was part of the water which flowed along under the ice in the shallow side of the glacier and was diverted into some channel or crevasse which ended in the ice-front. During our stay the mouth of the stream steadily sank, until it was on a level with the water of the inlet. This may have been due to either of two causes: (1) the course of the channel may have been upward as it approached the ice-front, so that as the ice melted and broke away the section exposed was at lower levels; or (2) the stream may have deepened its bed by cutting and melting (see page 42, note).

On each side of the inlet large streams issue from the end of the ice at a number of points, and after rapid courses of between a mile and a mile and a half empty into the inlet, forming quite large deltas. These streams were about thirty feet wide and two feet deep. The current is so swift that they roll down stones as large as one's fist; but the principal material that they carry off is in the form of fine mud. We used this water largely in our camp, and found that although most of the mud would precipitate when allowed to stand for a few hours, still the water remained quite turbid even after three or four days. The muddy character of the water in the inlet a little west of the middle of the ice-front shows that another stream must discharge in that region, either under or through the ice. A small part of the drainage of the glacier passes down Main valley, but this does not amount to very much. I think the principal sources of the stream in this valley are from the snow-fields and smaller glaciers on its sides.

Moraines and Débris Cones.

The moraines of Muir glacier, seen from an eminence, are very striking. Coming from many quarters, they sweep in bold curves



MAIN ICE STREAM OF MUIR GLACIER, FROM V.

across the ice converging toward the inlet. Many of them rise 30 or 40 feet above the general level of the ice; but near the glacier's mouth they have become so diffused or have lost so much of their material in crevasses that they do not affect the general surface. In fact, the moraines which cross the crevassed region near the end of the glacier have almost entirely disappeared. It is only from an elevated point that they can be traced.

The moraines from the east are large and much massed together. A large moraine from the eastern side of the southeastern tributary curves around and entirely closes in the end of that glacier and unites with several moraines from its western side into a confused mass, which the time at our disposal did not permit us to separate. Among these moraines occurs the marble mentioned by Professor Wright. The moraines from White glacier unite with those just mentioned a short distance below its mouth, beyond which they approach closer and closer to the mountains. They look like huge earthworks holding up the clean ice of this tributary 20 or 30 feet above the general surface of the glacier. Dirt glacier is completely closed in by a moraine across its mouth. Above this comes a zone of comparatively clean ice, and then for a mile or more the glacier is so completely covered by débris that no ice can be seen. Girdled glacier also is completely hemmed in by a moraine.

The next group of moraines, coming from Main valley and Granite canyon (see plate 10), unite near *I*, where they are apparently reinforced, and finally flow down the steep slope east of the ice-front. These moraines are quite different from any I have ever seen or read of. They have two ends, but no beginning. From the region lying between Tree mountain and Granite canyon the ice slopes in both directions toward the glacier's mouth and into Main valley. The former slope, as has been said, is a little over 1° ; the latter is two or three times as much. Two of the moraines have their upper terminations in Berg lake; a third ends in Main lake. To this group belongs also a moraine which issues from Granite canyon, flows around Girdled glacier, and ends against the side of the mountain a short distance down Main valley, or follows the mountain side to Berg lake. Another moraine, issuing from Granite canyon, curves as though about to flow into Main valley and then abruptly changes its direction and flows to Muir inlet (see plate 11).

A large moraine stretches from nunatak *H* to the corner of the

ice-front and then scatters over the projecting wing. At first sight the nunatak seems to furnish the material of this moraine, but closer observation shows that this is not so. Mr Cushing called my attention to the fact that although the material of this moraine is largely dark igneous rock, the nunatak is a light granitoid rock; and, moreover, the débris on the nunatak is almost entirely of the same rock as the nunatak itself. Two moraines issuing from the east side of the first northern tributary come to an end about half way between Snow dome and *H* (an explanation of these moraines appears on page 36. The remaining moraines are like those with which we are familiar on other glaciers, and call for no special mention. Some must be over 20 miles in length. Their origins are lost in the snows of the higher parts of the glacier. Sand cones and glacier tables also occur where the conditions are suitable.

The moraines from *I* end in a long sharp ridge, the ice of which is hidden by only a thin covering of stones of small size. There are two other similar ridges between this one and the side of the glacier, which, however, are not connected with moraines. All the large-sized débris seems to have slid off the steep side and left only the smaller fragments. South of the eastern end of nunatak *G* we found two very curious cones of rolled stones. The stones were about the size of billiard balls and rested on the ice underneath just at the angle of repose, so that the slightest disturbance, such as a little melting of the supporting ice, would cause some to roll down. Their edges were rounded, and they presented exactly the appearance of having been knocked about by running water. Their uniform size shows that some agent has been at work rejecting both smaller and larger pieces. Perhaps they were collected by a stream at some point on the side of *G* and an avalanche carried them out upon the ice. Other cones occur near these, but are not composed of similar material.

Former Extension and recent Diminution of the Glacier.

Professor Wright has pointed out the facts which show that Muir glacier has been both much larger and much smaller than it is at present. The existence of erratics, rounded knobs, and glacial scratches at points considerably above the present level of the ice shows the first; the existence of the buried forest on the western side of Muir inlet and of old logs on some of the moraines show the latter. He has also collected the following

MOUNT WRIGHT, FROM V.

evidence to show that the glacier is at present retreating, and that its retreat is quite rapid, viz: The absence of forests in the upper part of Glacier bay, the existence of fresh striæ and of glacial débris in situations where the material could not have resisted erosive agencies for any great length of time, the small amount of débris fallen from the mountains on the eastern side of the inlet, the small amount of vegetation on the shore near the glacier, the transverse ridges on the shore, the mass of detached melting ice in front of the glacier, and, finally, the account of Vancouver, which makes it probable that a large part of Glacier bay was filled with solid ice a hundred years ago.*

To these evidences I may add the following observations: On the sides of the mountains bordering the glacier, and especially in the gullies on the northern slopes, there are masses of ice extending a hundred feet or more above the present level of the glacier. This ice has been protected from very rapid melting by the débris which covers it. It must have been a connected part of the glacier not many years ago. On the northeastern side of Tree mountain there is a spur which projects into the ice of Main valley. On its upper side and near its end the ice is only some 10 or 20 feet below its top; on the lower side the ice is much lower. Across this spur in a direction parallel to the valley were some small stream beds, beginning abruptly at the upper side, whose source must have been the melting ice when it was level with the top of the spur. The whole spur was covered with bowlders, sand, and some fine detritus. The stream beds were marked only by the disposition of the sand. The fine detritus must assuredly have been washed away by the rain and melting snow if the spur had been uncovered many years. The ice between *G* and the nunatak to the west is at a higher level than the western or northwestern tributaries and slopes both toward the north and the south. As this region has no independent source of supply, it must have obtained its ice from the northwestern or western tributaries, which therefore must have been at a higher level than they are now. If this subsidence had been due entirely to melting, the surfaces of these two tributaries would not have sunk more rapidly than that of the ice connecting them. We are therefore forced to conclude not only that the ice is melting away, but also that it is flowing away. This process has

* Ice Age in North America, 1889, pp. 51–57.

been noticed among the Swiss glaciers by Forbes and by Agassiz as a seasonal change, the glacier partly flowing away during the summer and thickening up again during the winter. The loss incurred in this way by the Muir glacier in the summer is not made up during the ensuing winter, for the difference in level just mentioned is far too great to have been produced in one season.

The stratified deposits on the shores of Muir inlet are covered by a thin layer of moraine a foot or two thick; scarcely thicker, in fact, than the moraine which covers the end of the glacier. If the ice had not retreated rapidly this deposit would have been much thicker. The mass of detached ice mentioned by Professor Wright has entirely disappeared.

The moraines extending from the lakes in Main valley to Muir inlet seem explicable only on the supposition that this valley once contained a glacier tributary to the Muir, and that the supplies of snow having diminished in this region more rapidly than in the northwest this tributary has diminished much more rapidly than the Main glacier, until now the flow is actually reversed. The two moraines issuing from Granite canyon and flowing one into Main valley and the other into Muir inlet are also due to the same cause. The moraine extending from *H* to the ice-front, and composed of material quite different from the granitoid rock of *H*, is readily explained by the former greater thickness of the ice. The moraine which comes from the first northern tributary probably flowed just over *H*, and when the ice here was not very thick the very steep southern face of *H* must have caused a break in its continuity, so that the ice and moraine fell over this slope to the surface of the glacier below. The accumulation of detritus here is the source of this moraine, and it has not yet been entirely carried off.

In a valley connecting the western side of Muir inlet with the upper part of Glacier bay there lies a small glacier which we have called Dying glacier. It is about 3 miles long, slopes both eastward and westward, and has moraines running from end to end. It has no real feeders, although a tributary joins it on the south. It must be the remnant of a much larger glacier, deriving its supplies from the lateral valleys; probably also, perhaps principally, from the great ice stream which filled the upper part of Glacier bay, with which it must have had connection. At present its highest point is 760 feet above tide, an elevation much

MOUNT YOUNG.

lower than the surface of the ice when at its greatest flood. It is now without supply, and is rapidly melting away.

Another element of the diminution of the glacier, and one which would appeal much to most persons, is the retreat of the ice-front. In the four years between Professor Wright's visit, in 1886, and my own, in 1890, the ice-front receded more than 1,000 yards (see further, page 41).

Extent and Date of the last great Advance.

On the northeastern side of Tree mountain the lower slopes are covered with moraine débris and with very slight vegetation. At a height of about 2,000 feet above tide large trees (spruce) are found growing, some of which are quite a foot in diameter and must be over a hundred years old. Above this limit the mountain is free of erratics. On the opposite side of Main valley there is a very noticeable line about the same height, marked by a variation in the shrubbery, although there are no trees on these mountains. This, then, is the highest point reached by the glacier in this part. The rounding and scratches show that nunatak *G*, 1,855 feet above tide, was covered, as were also the islands in Glacier bay, one of which (Willoughby) is 1,000 or 1,500 feet high. The height of scratches and erratics in the neighborhood of the glacier's mouth we did not determine, but the height given by Professor Wright (2,500 feet) seems to me a little too high. At *V* (3,000 feet) no erratics were found, and as the ground here is well adapted to retain them we must conclude that the glacier did not rise to this height. I am inclined to think the scratches observed by Professor Wright at a height of 3,700 feet* are due to local causes.

The advance of the ice from Muir and other glaciers of Glacier bay must have been near its maximum at the time of Vancouver's visit, 100 years ago, for it seems probable from his narrative that the ice extended below Willoughby island, and the large trees on the islands in the lower part of Glacier bay show that it did not extend that far. That the height given, 2,000 or 2,500 feet, was that of the last great advance seems pretty certain from the freshness of the scratches up to that limit. Moreover, if at the

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*This would make the ice at this point several hundred feet higher than at Tree mountain, which is extremely improbable. Probably only a small error would be made if we take 2,000 feet as the maximum height of the ice near its present ending.

time of Vancouver's visit the ice extended below Willoughby island and had a front 300 feet high, it would have to be about 2,000 feet high on mount Wright to give a surface slope of 50′; and a slope of 1°, which is certainly not excessive, would correspond to a height of about 2,500 feet on mount Wright.

Another point is worthy of notice. From the divide between Tree mountain and Granite canyon the ice is flowing in both directions and is receiving no supply. The surface of the ice here is now about 1,250 feet high. If we suppose the surface melting at the rate of 2 inches a day (the rate observed near the glacier's mouth) for 90 days in the year, and if we entirely neglect the loss due to the flow of the ice, we find that it must sink about 15 feet a year. At this rate it would have been at its hightest, some 800 or 1,000 feet above its present surface, between 50 and 70 years ago; and if we also consider the loss due to flow, the greatest height must have been reached still more recently. This rate of loss could not have continued for a longer period or the glacier would now be lower than it is. It follows that from 50 to 70 years ago, or less, the rate of loss of ice in the region near Tree mountain was diminished by a supply which was undoubtedly derived from Main valley. This conclusion is supported by the moraines in main valley. They could not have retained their present course, flowing in two directions, for a long period without becoming very attenuated. Taking these facts into consideration, it does not seem unreasonable to believe that the greatest extent of the glacier was reached 150 or 200 years ago.

Evidence that the last Advance was of Short Duration.

I have already mentioned the stratified deposits on the shores of Muir inlet over which the ice now rides. We find a similar state of things at the eastern end of Dying glacier, where the ice rests on earlier deposits. In a gully on the northeastern side of Tree mountain the ice detached from the main glacier is resting on débris. Although sand and gravel form a pretty solid bed, it is hardly possible that they should have resisted the grinding action of the glacier for many centuries, especially when the ice was much thicker than it is now. Mr Cushing has called my attention to the fact that a gully on the eastern side of *H* and others on *G* do not correspond in direction to the glacial scratches, and therefore could not have been excavated by the glacier. Many geologists would consider this a proof of the inability of the glacier to accomplish much erosion; otherwise the

MORAINES EXTENDING FROM MAIN VALLEY PAST OPENING IN GRANT CANON.

sides of the gullies would have been planed down and these features obliterated. We can, however, equally well look upon it as evidence that the ice did not cover them for a very long period.

The trees of the buried forest (see plate 12) must have grown when the glacier was smaller than it is now. The sand and gravel was then carried in among them until they were completely buried, after which the glacier pressed forward and moved over the sand. Now, these trees are most probably of the same species as the spruce now growing in the neighborhood of Juneau (see supplement iii), and therefore it seems we should reckon the time elapsed since they were alive in centuries rather than in thousands of years. Another evidence lies in the logs found on moraines and on mountain slopes. We found them in the moraine in front of White glacier, on the moraine issuing from the eastern side of the first northern tributary, on the eastern shore of Muir inlet south of the stream, in the gully east of camp, and in gullies on the northeastern side of *G;* in fact, over most of the region about the southeastern part of the glacier. In these gullies they seemed much covered with débris, coarse and fine, which has apparently protected them from being ground up by the ice. Now, it hardly seems possible that this wood should not all have been carried away long ago if its origin had not been comparatively recent.

Before the advance the glacier must have been very much smaller than at present to allow the region about the first northern tributary, which is now bare and bleak, to support trees; and it must have remained smaller for several hundred years to allow the trees of the buried forest, some of which are two feet or more in diameter, to attain their size. A piece of one of these trees shows 22 rings in a thickness of one-third of an inch, which would give a rate of growth of one inch in diameter in 33 years. It seems probable that this very slow rate does not apply to the whole life of the tree, but only to its later years. The wood was from the outside.

Although the evidences indicating a short duration for the last advance of the glacier is not decisive, still this supposition seems to be in harmony with all the facts. Probably the principal objection that can be urged against it is that the changes are much more rapid than any we are familiar with. Let me, however, call attention to certain historical facts collected by Venetz and Agassiz, which show that during the middle ages, from per-

haps the tenth to the sixteenth centuries, the glaciers of the Alps were much less extensive than at present, and that horses were able to cross passes now considered difficult by mountaineers. During the seventeenth and eighteenth centuries the glaciers increased, attaining their greatest extent in the beginning of this century.* At present they are in general retreating. This shows a variation almost as great and almost as rapid as that mentioned for the glaciers of Glacier bay.

A possible Cause of the recent Retreat.

When the tide in Muir inlet is very low one can see on its eastern shore the stumps of large trees, which Professor Muir assures me are in place. The trees must have grown, of course, above high tide; they are now twenty feet below that level. Although I cannot say so with certainty, it is not unreasonable to suppose that these trees, like those of the buried forest, are spruce, and of the same species as those now growing in Alaska; but we must remember that any results deduced from this supposition have no more weight than the supposition itself. If, therefore, these trees were growing at the same time as those of the buried forest, there has been a subsidence of the land of at least 20 feet since the last advance of the glacier; it may have been much more; if so, it would have produced an increase in the mean annual temperature, which would have increased the rate of melting and would also have decreased the proportion of the solid to the liquid precipitation; and on account of the general lowering of the mountains, more of the moisture from the ocean may have been carried over them and precipitated further inland. All of these results would tend to diminish the extent of the glacier. Not only that, but the diminution itself would increase the rate of diminution, for the presence of extensive snow-fields must lower the mean annual temperature (see page 52) and thus increase the proportion of snow to the total precipitation. If for any cause these snow-fields become smaller, their influence on the mean temperature becomes less, the snow-fall is diminished, and the snow-fields become smaller still. So we see that anything causing a slight change in the mean temperature may result finally in quite a large variation in the extension of the glacier, although this large variation may reach its limit only long after the cause which started it has ceased to

*Agassiz, Etudes sur les Glaciers, 1840, chap. xvi.

GIRDLED GLACIER, FROM TREE MOUNTAIN.

act. The ends of glaciers are rarely stationary; they seem always to be advancing or retreating; the suggestions above show that this is just what is to be expected. In other words, glaciers are never exactly in stable equilibrium with the surrounding conditions.

Changes to be expected.

Main lake and Berg lake are now separated by a very short distance, and it will not be long before they unite. This will result in the draining of Berg lake, which event will probably be marked by a flood. The melting of ice in Main valley must be rapid, for the great extent of its termination there presents a large surface for melting. When this termination has receded two or three miles and the surface of the ice has sunk two or three hundred feet, the ice from the first northern and from the southeastern tributaries will probably be in part deflected into Main valley. The small lake which occupies a lateral valley opening into Granite canyon will probably extend as the ice diminishes and perhaps occupy a large part of the canyon itself.

Professor Wright has kindly sent me some photographs which he took of the glacier in 1886. By comparing these with our own we can readily fix on our map, within 100 yards, the position of the ice-front at the time of Professor Wright's visit. This shows that in the four years from 1886 to 1890 the western end of the ice front has receded 1,200 yards and the eastern end 750 yards. The center also has receded about 1,200 yards, so that the average recession of the ice-front is a little over 1,000 yards in four years or, say, a mile in seven years. Professor Muir writes me that the notes of his first visit to the glacier in 1879 show that the ice then extended about to our station *D;* the rate of retreat deduced from this accords fairly well with that given above. The ice-front, therefore, must have extended as far as island *C* 20 years ago. Below *C* I think the retreat was more rapid; for there the glacier presented a much wider front to the water from which a correspondingly larger quantity of ice must have broken off, and this could hardly have been entirely compensated for by a greater velocity of flow on account of the many obstructions in the neighborhood of the present position of the ice-front. It does not seem at all incredible that the ice from the various glaciers of Glacier bay may have united to fill a large part of the bay a hundred years ago. Professor Wright's

interpretation of Vancouver's description seems perfectly in accord with what our observations would lead us to conclude.

The retreat is probably not regular but faster some years than others, and even varies considerably at different parts of the same season. For two or three weeks in August, 1890, there was scarcely any fall of ice; in the two weeks following the fall was so rapid that a great bay fully a quarter of a mile deep was made in the eastern part of the ice-front, which was before this only slightly concave. Plate 13, from a photograph taken on September 7, 1890, shows this indentation. I have collected on the map (plate 15) the positions of the ice-front at several periods; this shows the retreat at a glance much better than it can be described in words. The changes in the shape of the front will also be evident.

The present rate of recession of the ice-front in Muir inlet, a mile in seven years, will probably be exceeded in the near future; for it has reached a point where the conditions change. The deposits which support the wings are almost at the water level at the ice-front, and slope down at an angle of 6° or 7°; a little further back they will be below the water level and the ice-front will be broader, resulting in an increased amount of loss by breakage and hence a more rapid retreat. Ten or 15 years will probably see Dirt glacier on the east and the western tributary on the west entirely separate from the main ice stream.

Dying glacier is rapidly disappearing; in 15 or 20 years I think its bed will be empty. The maps I have made will enable us to determine with considerable accuracy the amount of these changes in the future. I should, however, say that although the northern end of Main lake is in its right place, the southern end is only approximately determined. The ends of Dying glacier are also only approximate.*

* Note added November, 1891. From photographs and descriptions sent me by Miss E. R. Scidmore I find that there have been some changes in the ice-front in the past year. The northwestern corner seems to have advanced slightly; the northeastern corner has receded 50 or 100 yards, and the rest of the front, which is nearly a straight line, has retreated some 300 yards since July 26, 1890. It is not, however, quite so far back as the extreme end of the bay formed just before we left in 1890. The stream which issued from the ice at the northeastern corner now comes out from under the wing and rushes across the beach, which it thus separates from the ice-front. The large glacial stream on the east will undoubtedly follow the channel of this stream before long and fulfill Professor Wright's prophecy (Ice Age in North America, p. 54).

BURIED FOREST.

Motion of the Ice.

I had hoped to make an extended series of measurements of the motion at different parts of the glacier, but the pressure of other work and the great extent of the ice forced us to be content with a measure of the motion near the mouth. The reported motion of 70 feet a day was so great that we felt that careful precautions must be taken to avoid all error. We determined not to trust to sighting on pinnacles, but to set out a series of flags whose identity could not be mistaken. The middle part of the glacier is deeply crevassed, and in reaching the proper positions for planting the flags considerable difficulties were met; but, as in all such matters, this only added zest to the undertaking, and we set ourselves to the task of crossing the ice near its end. In this we were unsuccessful, although when setting out the flags we made five or six attempts, first from one side and then from the other. The furthest points reached from opposite sides were about 500 yards apart, and although this interval is greater than we wished, still it is not much greater than the average interval between the flags; and so our series was practically continuous (see map of ice-front, plate 15).

Two independent sets of measurements were made, the first on a series of ten flags from July 21 to 24, the second on a series of nine flags from August 4 to 8. The first three flags on each side were recovered after the first set of observations and replaced, so that observations on them extended from July 21 to August 8, a period of 18 days, with a corresponding increase in accuracy in the determination of their daily rate. Three or four days was about as long as the flags would stand before falling, although they were planted in holes 18 inches deep. The flags marked with one dash belong to the first period, those with two dashes to the second; the others were observed during both. No results were obtained from 7′, as it fell between July 21 and 24. The flags were observed from *E* and *K*, which were 5,513 yards apart, about three and one-quarter miles. These were the most available points of observation, and although they were not well adapted for determining with high accuracy the actual positions of the flags, still these positions were determined with quite sufficient precision. The direction of the motions could not be determined from our observations, for very small errors of observation produce large errors in this direction. This, however, was unimportant, for the direction is given by the moraines, which

was about at right angles to the line *E–K*. The change in the positions of the flags could be well measured from these stations, as the motion made a large angle with the lines joining the station to the flags. The part of this motion at right angles to *E–K* was taken as the actual motion. We have thus for the first period, July 21 to 24, two independent measures, one from *E* and one from *K*, which agree very well. The average is given in the table. For the second period, observations of motion were made from *K* only. The observations on the side flags from *K*, which extended from July 21 to August 8, are given in the column headed iii, and in the last column are collected what I consider the most reliable results. It will be seen that the motion, scarcely observable at the sides, increases rapidly toward the center, where it amounts to about 7 feet a day. A consideration of the size of the instruments, their distance from the flags, and the size of the flags themselves, shows that there is a possible, though scarcely probable, error of some two feet in the determination of the motion of the center flags, and not more than half so much in that of the side flags.*

Table showing Motion of the Flags in the Ice.

Flag.		Dist. in feet from—		Daily Motion of Flags, in feet.			
No.	Color.	*E.*	*K.*	I.	II.	III.	IV.
1....	Black..	13,622	4,321	.0	.7	.0	.4
2....	Red ...	12,064	5,850	3.0	2.3	2.6	2.6
3....	Black..	11,155	6,614	4.4	4.9	5.9	5.9
4″..	Red ...	10,384	7,438	......	6.6	......	6.6
4′...	Red ...	10,207	7,553	4.8	......	......	4.8
5′...	Black..	8,937	8,603	6.1	......	......	6.1
5″..	Black..	8,744	8,819	......	7.1	......	7.1
6′...	Red ...	8,498	8,921	7.2	......	......	7.2
7″..	Red ...	7,339	10,515	......	6.2	......	6.2
8....	Black..	6,378	11,106	5.7	6.9	6.2	6.2
9....	Red ...	5,226	11,936	4.3	4.8	4.9	4.9
10....	Red ...	3,652	13,275	.0	......	.7†	.7

I. Daily motion from July 21 to 24.
II. " " " August 4 to 8.
III. " " " July 21 to August 8.
IV. Best value of daily motion deduced from i, ii, and iii.

* The flags were six feet long and three feet wide. The instruments were those used in our survey and described later (see p. 53, foot-note).

† This determination was made from *E* for the period July 21 to Aug. 4.

In addition to the flags, five stakes were planted in a line and about equal distances apart on the eastern side of the glacier, as shown in the map. Their movement was determined from August 6 to 29. The table gives the total movement during that time at right angles to the line of the flags, which was the direction of the slope. The direction of the moraine shows that this is approximately the direction of motion.

Movement of Stakes.

a	0
b	7 inches.
c	11
d	3.5
e	0

This amounts to about 2″ a day for the middle flag.

Conditions holding at the Ends of Glaciers.

Alpine Glaciers.—It has been long recognized that the comparatively stationary position of the end of a glacier is due to the

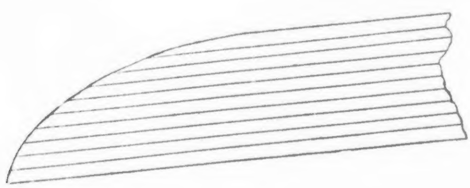

FIGURE 1—*End of an Alpine Glacier.*

general equality between the quantity of ice flowing down and the quantity melted. The mean temperature of a valley increases as we descend; if, therefore, the end of the glacier should advance beyond the point where the rate of melting equals the rate of supply, the ice would melt more rapidly and the end would recede. If, on the other hand, the glacier should not reach this point, ice would flow down faster than it would melt, and the end of the glacier would advance. This point is not merely a point of equilibrium, but a point of stable equilibrium. This explanation is sufficient, so long as we merely look upon the end of a glacier as a whole. But when we consider each part of the end by itself we are met by difficulties which do not seem so far to have been noticed.

As one approaches the end of the glacier the surface of the ice becomes steeper and steeper, and frequently becomes too precipitous to allow one to stand on it. The diagram (figure 1) shows the form of the surface cut by a longitudinal section. Now, why does the glacier assume this shape? We know that the surface of a drop of water or of a small quantity of honey on a plate will assume some such shape; but this is the result of molecular forces which can not have any appreciable effect on large bodies like a glacier. The end of a flowing lava stream will have a somewhat similar form, but this is a case of continued flow and not one of equilibrium. These analogies throw no light on the question. If we divide the glacier into layers by a series of surfaces parallel to the direction of flow, the condition that the end shall be stationary requires that the ice supplied by each layer shall be melted at its end. Now, the upper layers move more rapidly than the lower ones; therefore their ends must melt more rapidly. A glance at the diagram will show that, on account of the form of the end of the glacier, the ends of the upper layers expose a larger surface than the lower to the air and sun, resulting in their more rapid melting. This, although undoubtedly a part of the explanation, is not the whole of it, for the form of the glacier's end would be one of unstable equilibrium. If anything should cause the surface to become somewhat steeper, the exposed ends of the upper layers would become smaller, and these layers would no longer melt away rapidly as they advance; the surface would continue to grow steeper until the upper part would break off and thus restore the slope. Although glaciers have been observed to advance I have never heard of it occurring in this manner. A series of measurements of the rate and direction of motion, and the rate of melting at the end of some glacier, such as the Gorner or Morteratsch, in Switzerland, would undoubtedly throw light on this problem.

At the end of the valley of Norris glacier, Taku inlet, there is a broad expanse of gravel, etc, on which the glacier, after issuing from its gorge, spreads itself like a great fan, thus presenting a large surface to the air and sun; so that the melting of the ice is as rapid as the supply.* If it were prevented from spreading it would extend much further than it does, and would undoubt-

* This level expanse must be either the accumulation of glacial débris or a delta formed when the glacier was less extensive than now.

END OF MUIR GLACIER, FROM V.

edly reach deep water. The Taku glacier, close by, finds no such support at the opening of its gorge, and therefore discharges into the water as a tide-water glacier. Davidson glacier, Lynn canal, has a termination exactly like that of the Norris. The great Malaspina glacier seems to be merely the united ends of the many large glaciers flowing from the St. Elias alps, expanded on the great plateau which borders these mountains on the south.*

Tide-water Glaciers.—The Muir glacier is an excellent example of this class. The inlet into which it pours increases in depth from the sides to not less than 720 feet near the middle; but the ice is so thick that even this depth is not sufficient to float it. Here we have an entirely different method of waste. The ice breaks off and floats away in the water as icebergs. What is it that regulates the rate at which the ice breaks off? What is the form of the glacier's end below the water? Above, it is practically vertical. I can only give a partial answer to these questions.

Suppose the end of Muir glacier were vertical from top to bottom; let us apply what we know of the motion of glaciers to this case and see what would follow. The more rapid motion of the upper part would result in its projection beyond the lower part, and this would become greater and greater until its weight was sufficient in itself to break it off. The extent of the projection before a break would occur depends evidently on the strength of ice. The water supports the ice by its buoyancy, so that the weight tending to cause fracture is slightly less than the weight of that portion of the ice which is above water. The line of fracture is determined by the position of some crevasse or some irregular melting below the surface. This form seems to be one of stable equilibrium, for if the ice should project too far it would break off, and if it did not project far enough no break would occur until its proper motion had carried it out further. That the ice for several hundred feet below the surface does not in general project further than that above is evident from the fact that I have frequently seen large masses, extending to the very top of the ice-front, shear off and sink vertically into the water, disappear for some seconds, and then rise again almost to their original height *before* turning over. If there were any projection within 300 feet of the surface, this mass would have struck it and

*See Russell, Exp. to Mount St. Elias: Nat. Geog. Mag., vol. iii, 1891, p. 121.

been overturned so that it could not have arisen vertically out of the water.

Let us picture to ourselves what takes place at the end of the glacier, noting first that there are three ways in which the ice breaks away: (*a*) a piece may break off and fall over—this is the usual way with small pinnacles; (*b*) a piece may shear off and sink into the water—this is the usual way with the larger masses; or, again, (*c*) ice may become detached under water and rise to the surface. The diagrams in figure 2 illustrate what I conceive to be successive forms of the ice-front. They show how, after a number of pieces break off from above, one large piece will break off from below, but, in all probability, not from near the bottom. The broken line shows where the break occurs. The dotted lines show the form of the front just after the last break.

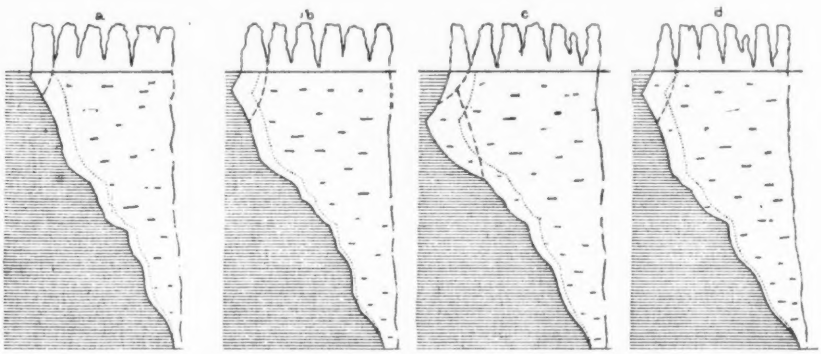

FIGURE 2—*End of a Tide-water Glacier.*

In addition to waste by breakage, there is the waste by melting. Above the water surface this is unimportant, for there the quantity of ice floated away is much greater than that melted; but near the bottom of the glacier, where the motion is very slow, the melting is the principal, probably the only, cause of waste, for the ice is in contact with water which is probably not very cold* and is, moreover, salt. That the ice does melt

* Professor Wright found the surface water in Muir inlet to be 40° F. I did not take the temperature, but I was once much astonished on putting my hand into the water to find it not at all cold, although there was a large amount of ice floating about. This high temperature must be due to the tides and warm winds prevailing here, and to the comparatively warm sea near by.

below water more rapidly than it does in the air, is shown by the fact that icebergs roll over, which is due to this alone. It is quite possible that the icebergs darkened by mud and rock may not have come from the bottom, but may be merely exposing the side of some old crevasse into which débris from a surface moraine has fallen. The bergs which we saw rise from below the water usually came up after a very heavy fall from above, as though some crack had been started by the shock of the falling ice; only a few of them were discolored by débris; most were pure blue ice* Moreover, they did not rise very high out of the water. All this makes me think that they did not originate at any very great depth. Just as a stick thrown obliquely into the water may rise again at an angle, so a berg, on account of its shape, may rise so obliquely as only to reach the surface some distance from the ice-front, thus suggesting that the glacier sends out a foot along the bottom of the inlet, from the end of which the ice breaks off; but the considerations I have mentioned make it evident, I think, that this is not the case. A series of observations on the temperature and density of the water of Muir inlet at different depths and at different distances from the ice would undoubtedly afford information that would enable us to reason very accurately about the form of the ice-front below the water.

The ice at the bottom of the glacier in contact with its bed moves very slowly, and it is not improbable that the melting, where it meets the salt water, quite equals the advance. The slope from that point up is determined by the strength of the ice. If the progression of the bottom is greater than the rate of melting, the glacier will advance until it comes to a broader part of the fiord, and thus presents a broader front to the water. If the fiord were of uniform depth and breadth, the ice could only find a position of equilibrium at one end or the other.

The effect of the depth of the water in determining the position of the glacier's end is not apparent. As the depth is greater the pressure against the ice is greater, but at the same time the water produces a greater upward pressure on the ice, diminishing its pressure against its bed and thus reducing the friction. Although these effects cannot balance at all depths, I am unable to indicate which one is in general the stronger.

* The discolored bergs seen by Mr Russell in Disenchantment bay are probably from the débris-covered parts of the neighboring glaciers.

If a glacier reaches water which is so deep that it does not touch the bottom, and the motion of the ice is more rapid at the bottom than the melting, then its end will be forced further and further into and deeper and deeper under the water, following the slope of the bed, until the buoyancy of the water is sufficient to break it off. The place where the fracture will occur, and the size of the iceberg formed, are problems of mechanics.

Glacial Erosion.

The general scratching and smoothing of rock by glaciers is familiar to all. Another method of erosion, not so generally recognized, was observed here. The spur of Tree mountain, which I have already mentioned and on which we camped one night, is a compact slate; parts of it were smoothed and scratched; other parts bore a confusion of mixed rock, the rock of the spur largely predominating; in still other places the bed-rock showed where angular pieces had been broken out, leaving holes which in some cases contained water. Near the summit of nunatak *H* is a rock-basin lake which must have been formed in the same way. It is about 40 feet long and 20 feet wide.* Its sides are much scratched; on one side the rock rises vertically eight or ten feet above the water. The rock which formerly filled this hole, separated probably by joints from the rock beneath, must have been torn out by the ice in its passage over the spot—not necessarily as a whole, but possibly by pieces. The rocks thus torn out are in part pushed by the glacier to its end, in part rubbed and ground into fine mud and carried off by the subglacial streams. This method of glacial erosion seems to me much more efficient in digging valleys than the simple scratching and smoothing that is so much more noticeable in valleys formerly occupied by glaciers.

Probably the best method available for determining the rate of erosion is to calculate the amount of sediment carried off by subglacial streams, as Professor Wright did. Repeating his calculation with the more accurate data at our disposal, we find that an average of about three-quarters of inch is eroded annually from the bed of Muir glacier.†

* These dimensions are given from memory.

† The following data were used in this calculation: Area drained by glacier, 700 square miles; area of glacier bed, 350 square miles. If we assume no motion at bottom, then in the middle of the ice-front the quan-

The erosion, of course, cannot be uniform, but must vary much with the nature of the rock and the thickness and rate of motion of the ice. Near the mouth of the glacier all of these conditions coöperate to increase the action, for the rock is slate, the motion more rapid, and the thickness of the ice probably greater than elsewhere. It does not seem excessive to consider the erosion here five or ten times as great as the average. The sudden fall between *G* and *H* probably marks the line between the harder

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tity of ice carried out per day would be a triangle of 7 feet base (see page 44) and 920 feet altitude. Near the sides the triangle would have a smaller base and a less altitude. Let us suppose a wedge having 7 feet base and 560 feet altitude (half the greatest depth plus the height of the ice above water) and a breadth equal to the whole ice-front, 9,200 feet, to be breaking off daily; let us suppose this daily loss constant throughout the year (our ignorance of the law of glacial motion below the surface will not permit a closer approximation—double this quantity would certainly be too much, and would still only slightly affect our result). The Signal service sends me as the average of six years' observation of rainfall at Sitka 105.62 inches, and the average at Juneau 89.30 inches. Our own observations at camp Muir for two months gave about the same rainfall as at Juneau for the same period. I have therefore adopted 90 inches for the yearly precipitation (see appendix ii). The rest of the data I have taken from Professor Wright's account (Ice Age in North America, p. 64), viz: 708.48 grains of sediment in each United States gallon of water of the subglacial streams; specific gravity of this material, 2.5; loss by evaporation, one-eighth of precipitation. We thus find for the total precipitation over the area drained by the glacier, 146,300,000,000 cubit feet; annual loss in bergs reduced to water, 5,906,000,000 cubic feet; loss by evaporation, 18,300,000,000 cubic feet; leaving, say, 120,000,000,000 cubic feet of water per year carrying off sediment, which gives an average of about ¾ inch eroded from the whole bed of the glacier. It is assumed that all the water coming from the glacier is charged with sediment. This is in accord with observations so far as they go. The clean surface streams near the end of the glacier empty into the subglacial streams, from one of which the determination of the amount of sediment was made. It may be objected that much of this sediment comes from the surface moraines, the rocks either there disintegrating into fine material or falling through crevasses to the glacier bed and being there ground up. The clearness of the surface streams show that the former is not the case; and the fact that all the moraines on the surface of the glacier would hardly be enough to supply material equal to the sediment carried out in a single year is conclusive evidence against them both. We have not taken into consideration the material pushed out from under the glacier before it has been ground fine, and this is probably of large amount (although we have no means of measuring it) and would increase the above estimate of the erosion.

crystalline rock above and the softer slate below, and is probably due to the different rates of erosion of these rocks.

Meteorological Notes.

The prevalent wind on the Alaskan coast is from the southwest, but the glacier, by cooling the air in contact with it, produces a cold wind which slides down its slope. Thus a northeasterly wind blew continuously at our camp except occasionally when a strong southerly gale overcame it. On the western tributary the wind was from the west and in Main valley from the northwest; in fact, everywhere it flowed down the slope of the glacier. Its influence on the temperature was very marked. The mean temperature during July and August was 45°.1 F., about 10° lower than that at Juneau during the same period, although this latter place is only about 35 miles further southward. At no time during our stay, however, was a freezing temperature reached.

This cold wind did not usually extend very high; frequently mist could be seen moving northward not 1,000 feet above our camp, where the flag was streaming toward the south. The

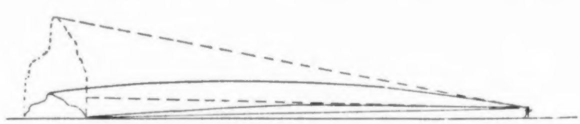


Figure 3—*Diagram illustrating Refraction.*

temperature was higher on elevations than lower down. At *V* (3,000 feet) the thermometer was once observed 6°.7 C. (12° F.) higher than at camp; also, at the same time, on the top of Tree mountain (2,700) the temperature was 4°.3 C. (7°.7 F.) higher than at camp. The increase of temperature with altitude causes an unusually rapid decrease of density in the atmosphere, with a corresponding increase in refraction, thus producing the mirage which is so common here. It is noticeable only when both the observer and the object are in the cold layer. A ray of light may reach the observer after following a horizontal path, or after rising slightly and then being refracted down again. The result is to make the object appear stretched out and to give it increased height. We often saw islands with apparently vertical sides; the icebergs in Glacier bay were magnified vertically so as to

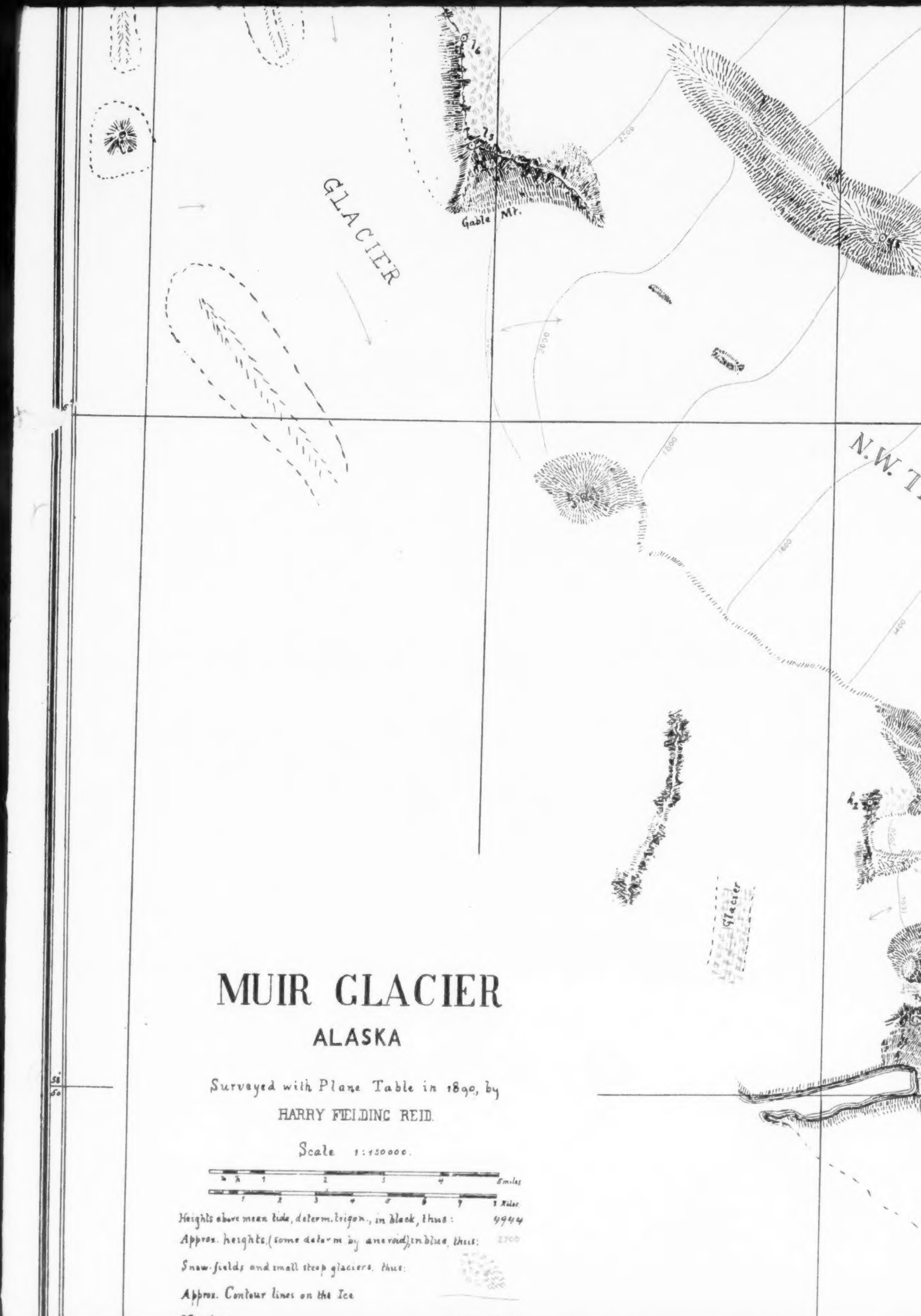
40'
30'
20'
59°
10'
3200
2800
2600
3400
2200
Gable Mt.
GLACIER
N.W. TR


10'
136°
Black Mt.
2nd N. TRIBUTARY
1st N. TRIBUTARY
MUIR GLA
TRIBUTARY.
Snow Dome
3200
3600
3200
2800
2800
2400
2400
2400
2200
2000
2000
1800
1800
1800
1800
1600
1600

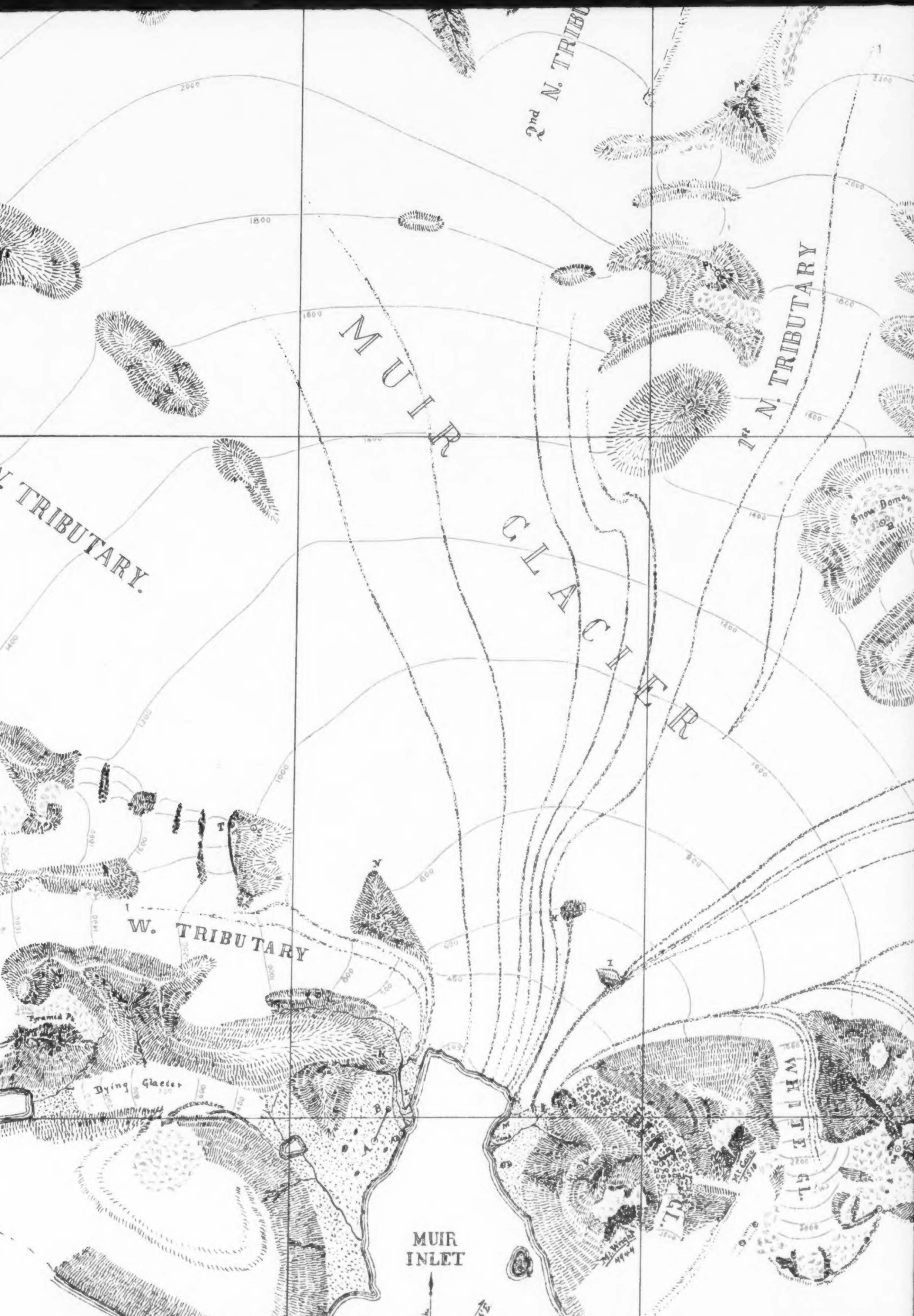
10'
136°
3200
3600
2800
Black Mt.
2400
2000
1800
1600
2nd N. TRIBUTARY
1st N. TRIBUTARY
MUIR
CLA
W. TRIBUTARY.
Snow Dome

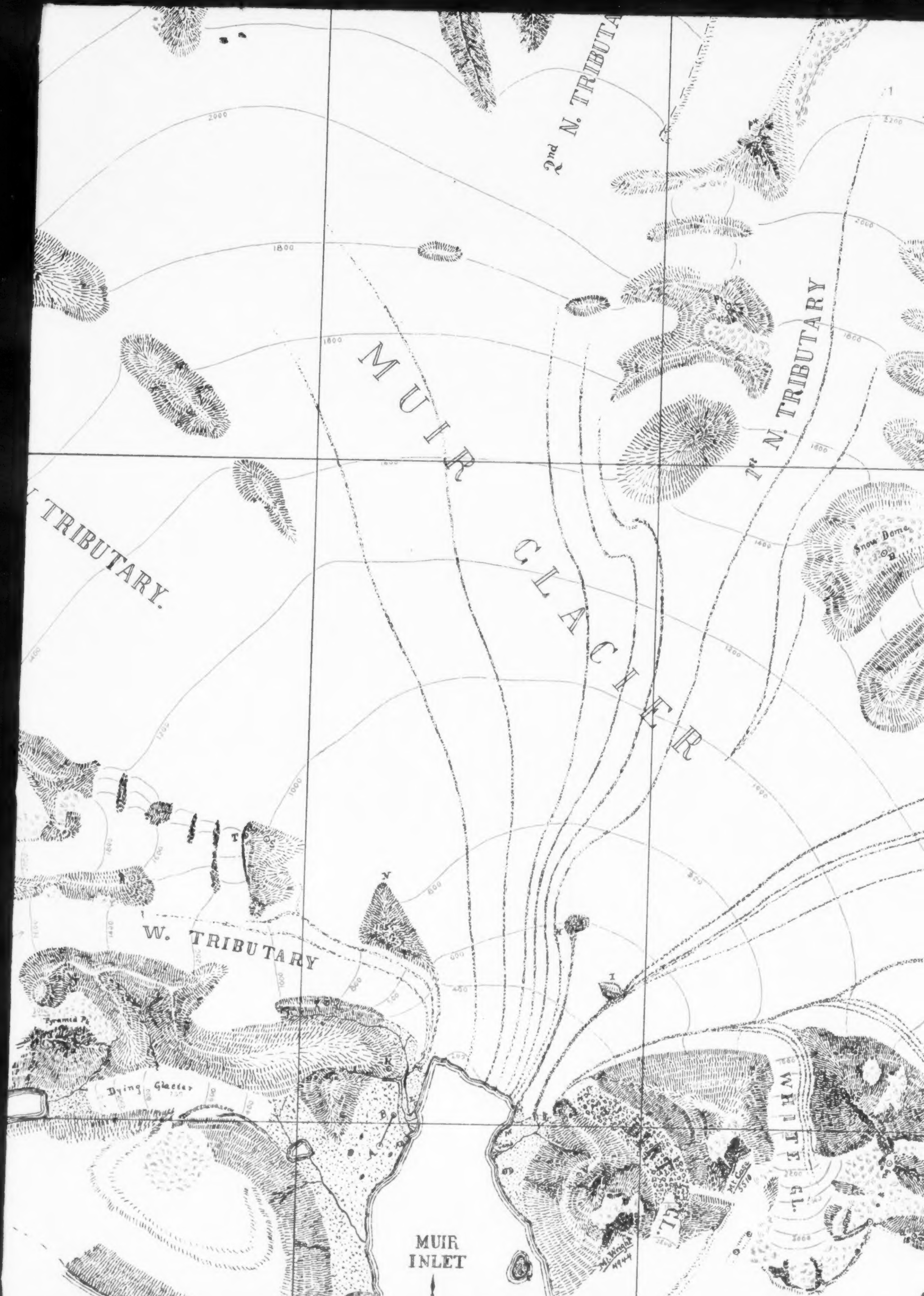
XUM


50'
135°
40'
59°
10'
7135
6543
2500
2400
Lake
Dome
NITE CANON



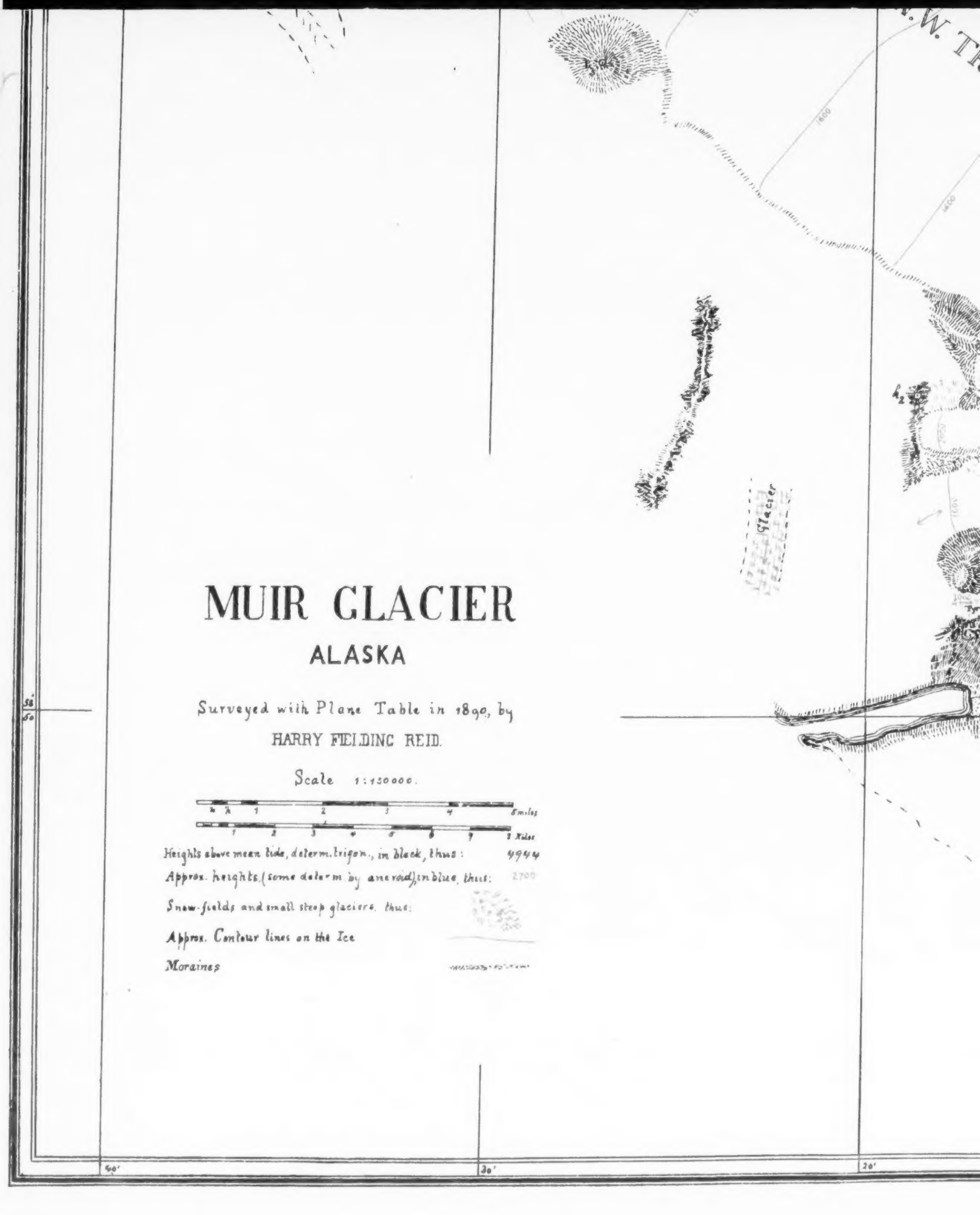
GLACIER
Gable Mt.
N.W. T
Glacier
MUIR GLACIER
ALASKA
Surveyed with Plane Table in 1890, by
HARRY FIELDING REID.
Scale 1:150000.
5 miles
8 Kilos
Heights above mean tide, determ. trigon., in black, thus: 4944
Approx. heights, (some determ by aneroid) in blue, thus: 2700
Snow-fields and small steep glaciers, thus:
Approx. Contour lines on the Ice
Moraines


2nd N. TRIBUTARY
1st N. TRIBUTARY
MUIR GLACIER
TRIBUTARY.
W. TRIBUTARY
Snow Dome
Pyramid Pk
Dying Glacier
WHITE GL.
Mt Case
Mt Wright
MUIR
INLET
North
30°26'E
2000
1800
1600
1400
1200
1000
800
600
400
2200

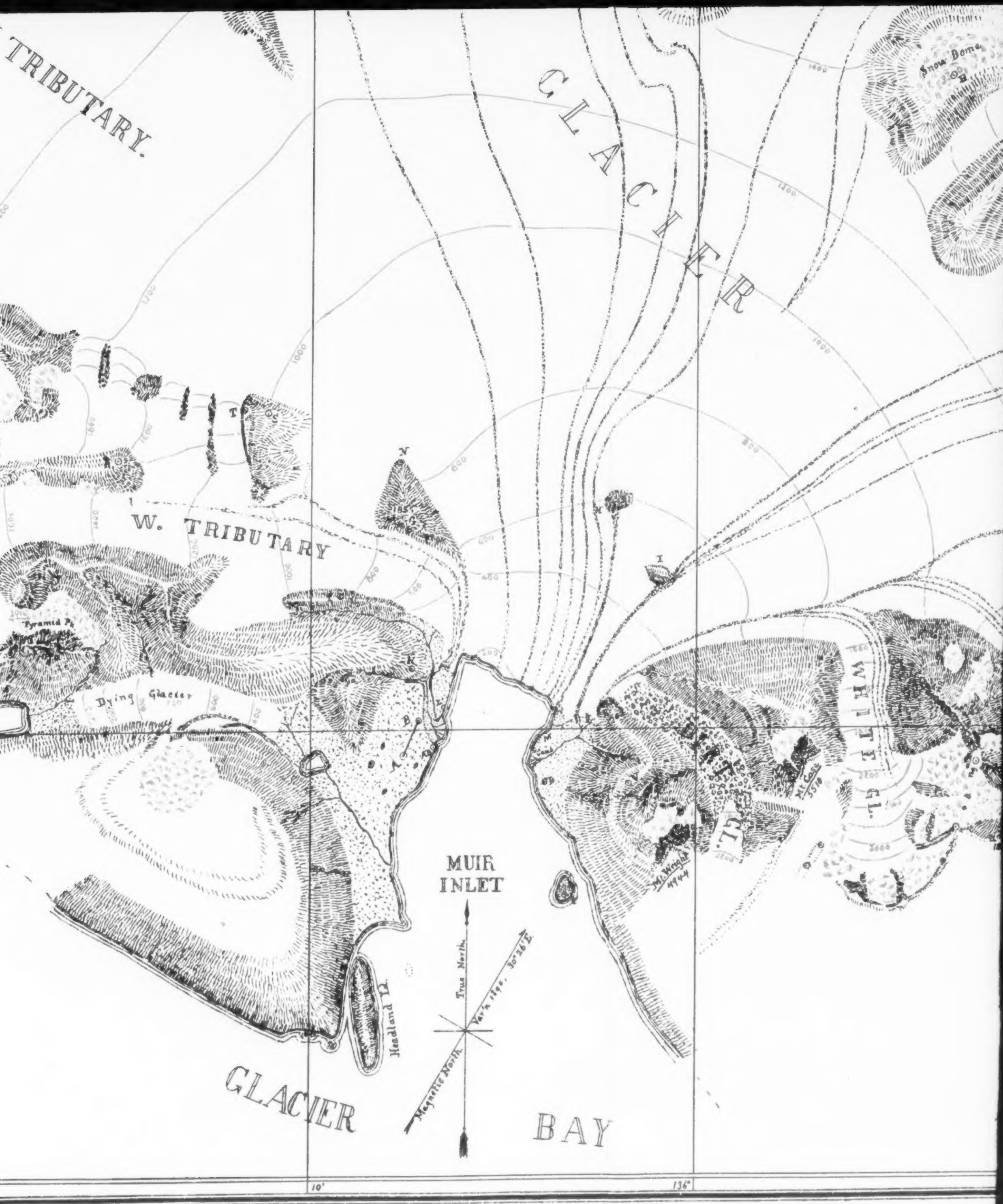


2nd N. TRIBUTA
MUIR GLACIER
1st N. TRIBUTARY
TRIBUTARY.
Snow Dome
W. TRIBUTARY
Pyramid Pk
Dying Glacier
WHITE GL.
MUIR
INLET
2000
1800
1600
1400
1200
1000
800
600
400

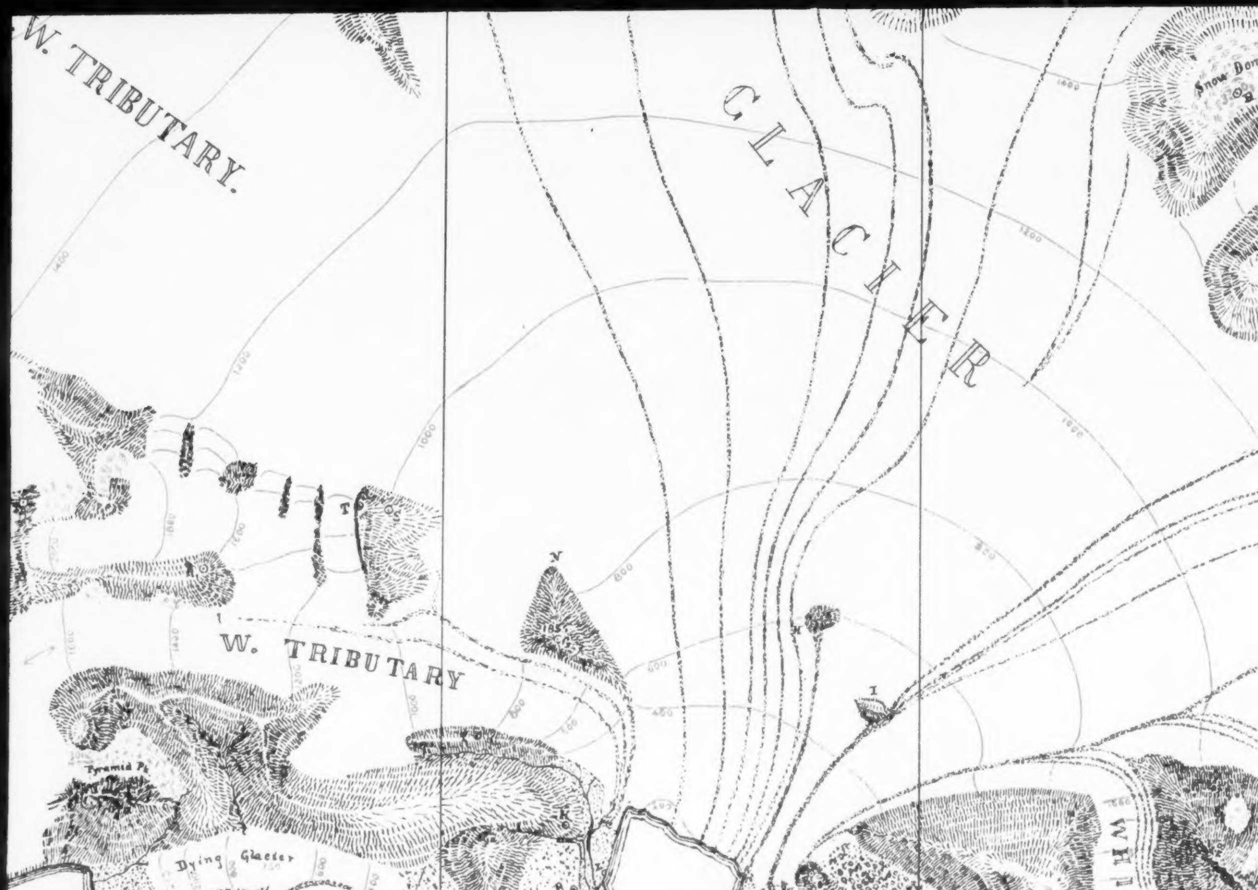

GRANITE CANON
Girdled Glacier
MAIN VALLEY
Berg Lake
Main Lake
S.E. TRIBUTARY
Lake
Mount Young
6545



MUIR GLACIER
ALASKA
Surveyed with Plane Table in 1890, by
HARRY FIELDING REID.
Scale 1:150000.
5 miles
Heights above mean tide, determ. trigon., in black, thus: 4944
Approx. heights, (some determ by aneroid), in blue, thus: 2700
Snow-fields and small steep glaciers, thus:
Approx. Contour lines on the Ice
Moraines
Glacier
N.W. T
40'
30'
20'

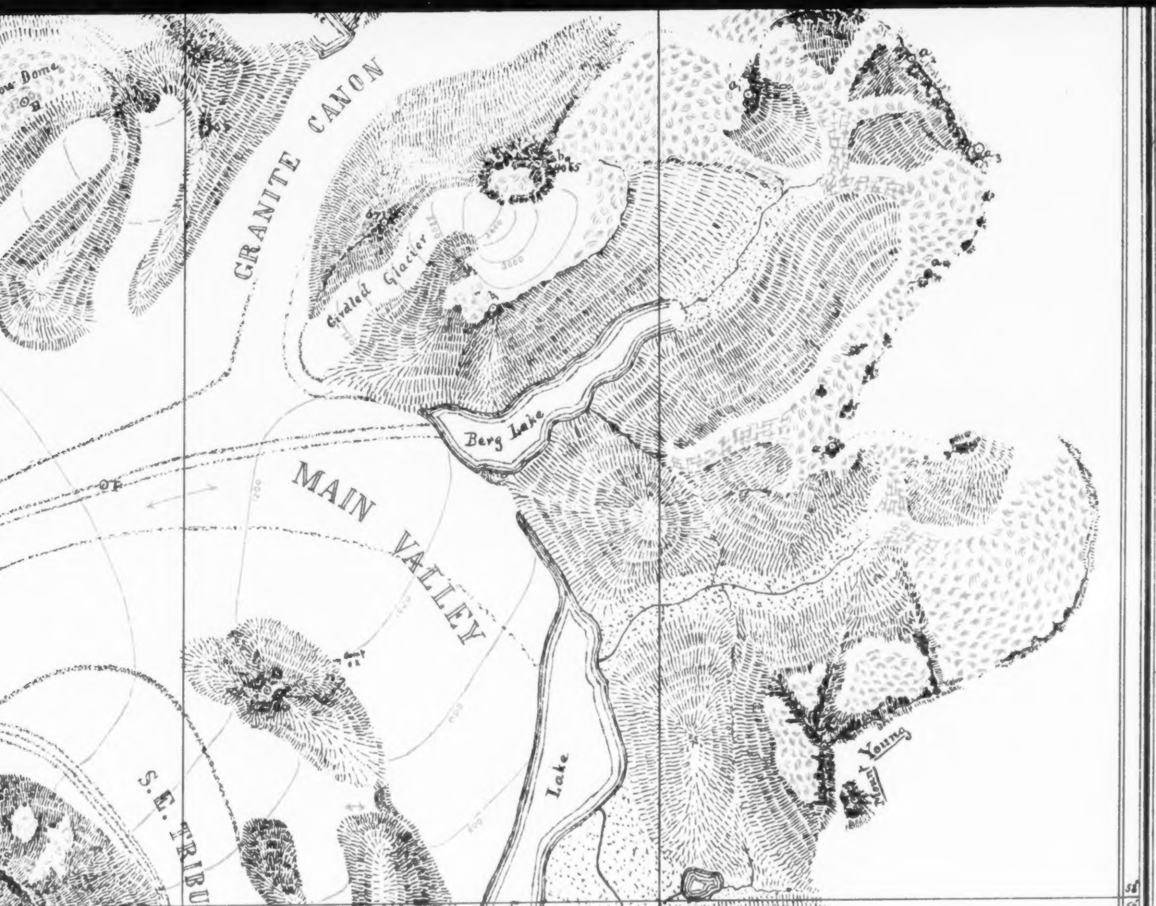


TRIBUTARY.
GLACIER
Snow Dome
W. TRIBUTARY
Pyramid Pk
Dying Glacier
WHITE GL.
MUIR
INLET
True North
Magnetic North
Headland Id.
GLACIER
BAY
10'
136°



W. TRIBUTARY.
GLACIER
Snow Dome
W. TRIBUTARY
Pyramid Pk.
Dying Glacier
WHITE GL.
Mt. Case
Mt. Wright
MUIR INLET
True North
Magnetic North
Headland Id.
GLACIER
BAY
10'
136°

XUM



GRANITE CANON
Dome
Girdled Glacier
Berg Lake
MAIN VALLEY
S.E. TRIBUTARY
Main Lake
Mount Young
58°
50'
50'
135° 40'

look like the ice-front of another glacier; the pinnacles of Muir glacier sometimes look like minarets. These appearances have given rise, by a considerable stretch of the imagination, to the so-called "Silent city," or "Phantom city," figured in some books which describe this region. This mirage is just the opposite to that seen in hot deserts. There the rays are bent up, making the image look as if it were reflected from the surface of water; here the rays are bent down; yet the bending is not sufficient to entirely separate the image from the object, but only makes the latter appear distended, as though it were made of rubber and had been stretched upward.

We had rather less rain than we expected; about one day in three was rainy during July and August; September was much wetter. There were no thunder-storms, and usually the rain was in small drops. In August auroræ were frequently seen, so frequently that I think they must have occurred every night; possibly all the time, although, of course, daylight would have masked them. Earlier in the summer the twilight, which lasted all night, would also have drowned them if they occurred.

The Survey.*

A base line was measured off with a steel tape from *A* to *B* on the plateau on the western side of the inlet; here we found fairly even ground The base was measured twice; first from *B* to *A*, then from *A* to *B*. The two values obtained were 962.301 and 962.330 meters respectively. The length adopted was 962.32 meters, = 1,052.8 yards. By means of small transits we then made a network of triangles and fixed the points *A B*, *D*, Camp, *E*, *K*, *L*, *M*, *b4*, *c2*. The maps were made entirely with the planetable. This instrument was set up at Camp, *D*, *E*, *H*, *L*, *N*, *O*, *P*, *R*; *S*, *T* and *V*, for the general map. The map of

*The instruments used in the survey were lent by the United States Coast and Geodetic Survey. They consisted of—1, a 30-meter steel tape, with which we measured the base line; 2, two small Casella transits, with 2¾-inch vertical and horizontal circles, divided to half degrees and reading by two verniers to minutes, which were used in the triangulation, in the measure of the motion of the ice, and in determinations of latitude; 3, a planetable 14 by 18 inches, with which the maps were actually made. In addition, we had four aneroids, only one of which, however, was found to yield reliable results This one was used in determining the height of *V*, and the height of the glacier near *P*.

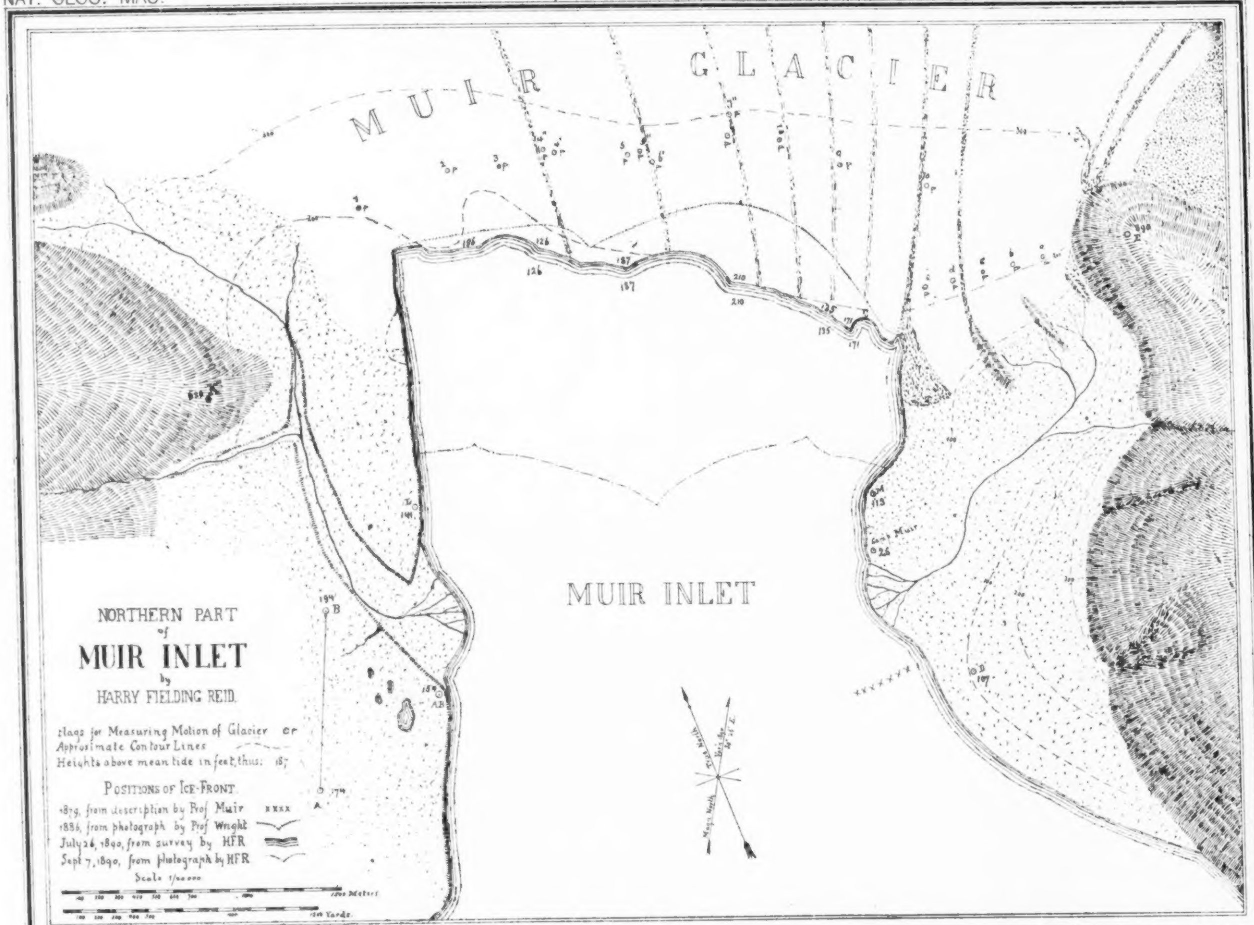
the inlet and ice-front was made from Camp, *D*, *L* and *M*. Photographs were made from many points, and these have been of the greatest use in drawing in the general topography. As to the accuracy of the maps I think that none of the points marked thus ⊙ are out of their place by 1 % of their distance from *E*; many are much more accurately fixed. Many points where the rocks and ice were in contact, etc, were, of course, determined, but with much less accuracy.

In order to connect our map with any future survey that may be made in this region, we made two cairns of heavy stones, one at *D* and one at *E*. *D* is on the gravels on the eastern side of the inlet, at a height of 107 feet above mean tide. *E* is on a flat knoll of the ridge descending from mount Wright, at an elevation of 890 feet. The horizontal distance between *D* and *E* is 2,735 yards, and the line connecting them runs N. 41° 43′ E., astronomical.

The latitude of our camp was determined on several occasions; the average, 58° 49′.7, can hardly be in error by more than a half minute. The longitude was not determined; on first going into camp the chronometer was allowed to run down, and when we left, it stopped for some reason unknown. The chronometers of the steamers were not sufficiently accordant among themselves to give reliable results by comparison with our local time. The longitude adopted by reference to the best map of the region in the Coast Survey office is 136° 5′ W., which can hardly be in error by 5′.

On platting our map into the general chart of the United States Coast and Geodetic Survey, we see that the area we surveyed occupies much of the region between Lynn canal, Chilcat river, and the upper part of Glacier bay. The mountains on the eastern part of our map must be visible from Lynn canal, which is only ten or twelve miles distant. Davidson glacier must have tributaries in the mountains which close in Granite canyon. There is a rumor that the Chilcat Indians were accustomed to make the passage to Glacier bay over the Davidson and Muir glaciers. If this is true there is probably a low divide between some tributary of Davidson and the first northern tributary of Muir. This region, unfortunately, we were unable to see.

The scale of the general map is $\frac{1}{150000}$, which is large enough to show the detail we were able to make out, except in the neighborhood of the mouth of the glacier. I have added contour lines


MUIR GLACIER
MUIR INLET
Camp Muir
NORTHERN PART
of
MUIR INLET
by
HARRY FIELDING REID.
Flags for Measuring Motion of Glacier
Approximate Contour Lines
Heights above mean tide in feet, thus: 187
POSITIONS OF ICE-FRONT.
1879, from description by Prof. Muir
1886, from photograph by Prof. Wright
July 26, 1890, from survey by HFR
Sept 7, 1890, from photograph by HFR
Scale 1/20000
Meters
Yards

at 200-foot intervals; it must be remembered that these pretend to no accuracy, but merely serve to show the general form of the surface, as well as I can indicate it by aid of memory and photographs. The altitudes above mean tide which were determined trigonometrically are given in black figures; those determined by barometer or estimated, in blue figures. Camp Muir was estimated to be 25 feet above mean tide.

For the inlet I have made a separate map on a scale $\frac{1}{80000}$, which shows well the position of the flags we used for measuring the motion of the glacier and the form and position of the ice-front at various times. The contour lines here also are only very roughly approximate; the interval between them is 100 feet. The numbers give altitudes determined trigonometrically, except those on the contour lines, which are estimated.

SUPPLEMENT I.

NOTES ON THE GEOLOGY OF THE VICINITY OF MUIR GLACIER.

BY

H. P. CUSHING.

CONTENTS.

General Features.

Both aqueous and igneous rocks occur in the vicinity of Muir glacier, and the plutonic rocks belong to two distinct periods. All the rocks of the vicinity have suffered much dynamically, the recent eruptives excepted. The whole series is much shattered and fissured. Three sets of fissures are generally readily made out, dividing the rock into small prismatic blocks. These fissure planes are seldom vertical, but present varying angles. Generally they are mere cracks, often filled by infiltration, but sometimes they have a width of several feet. The numerous small dikes of andesitic rock appear to have the same directions as the fissure systems, and were probably formed at the same time. Evidence of small faults of comparatively recent origin, involving these dikes and determined by their aid, is occasionally forthcoming, showing a certain amount of disturbance in the region since they were formed. Evidence of earlier faults is difficult to obtain, owing to the homogeneity of the rocks and the

great difficulty in making determinations of dip on account of the obliteration of the bedding planes; but it is clear that a considerable amount of faulting took place prior to the formation of the dikes. The strike of the sedimentary rocks is about N. 50° W. (N. 80° W. magnetic). The dips are generally at high angles toward the south, but are extremely variable. Short monoclinals involving a considerable change of dip are not uncommon. Small anticlinals and synclinals occasionally occur, but are of minor importance, soon giving way to the prevailing southerly dip. These frequent variations in dip are well shown along the eastern shore of Headland island. A considerable fault is also shown about midway along this shore, clearly indicated by the difference of dip on the two sides; but the similarity of the rocks on both sides renders any determination of the amount of throw impossible. Sufficient country was not covered to at all clearly exhibit the type of mountain structure obtaining here. The dip is pretty persistently away from the diorite peaks, which were the most northerly ones reached. What lies beyond them no man knows. The work done makes it probable that we have here a tilted and raised block accompanied by faulting.

Sedimentary Rocks.

Two great series of sedimentary rocks are exposed in the Glacier bay region, one of argillite, the other of limestone; both are of great thickness. The limestonė is the younger. The contact between the two is well shown on the eastern shore of the bay, has an extremely steep southerly dip, and reaches tidewater about eight miles south of the present front of Muir glacier.

The Argillite.—The mountains adjoining Muir inlet and the upper northeastern shore of Glacier bay and those surrounding the eastern part of Muir glacier amphitheater are entirely composed of slaty rocks (see geologic map, plate 16). The thickness of these argillites I was unable to determine, but it clearly reaches several thousand feet. They present three main phases:

1. Very hard, fine-grained, gray argillo-siliceous bands, of somewhat varying shades, occasionally approaching quartzite in character.

2. Equally abundant with the last, and with them making up

the larger portion of the series, are bands of nearly equal hardness of a blue or black slaty rock, containing a smaller arenaceous admixture than the last, but being somewhat calcareous. The first variety is more abundant in the lower portion of the series, the second in the upper. Both are very homogeneous and fine-grained, and extremely compact. The black variety weathers to a dark-brown color, the gray to a yellowish brown and sandy-looking surface. These give characteristic colors to the moraines in the southeastern portion of the amphitheater, a medial moraine sometimes appearing one color or the other as it is viewed from one side or the other. The extreme hardness of these slates is due to their metamorphosed condition. The degree of metamorphism is quite uniform throughout. So far as can be told by the eye, it has nowhere been carried to a point where recrystallization has begun, so that none of these rocks are at all schistose in character. The metamorphism and the numerous fissures which cut these rocks have nearly obliterated the old bedding planes, so that dips are generally most perceptible from a distance, owing to the banded appearance given by the presence of the two varieties. Little or no tendency to split on the original bedding planes is now shown, the fissures determining the shape and size of the blocks, which themselves often display the color bands. These bands are well shown in many places; for example, on the highly glaciated slopes of mount Wright which face the inlet.

3. Comparatively thin bands of more fissile, black graphitic slates are found interstratified with the others. These are found at numerous localities, and there are certainly several such bands, though their apparent number may be increased by faulting. They are softer than the other slates, and readily split into thin, even slabs. They become dotted with brown specks on weathering. The fissures which intersect the slates are commonly filled, wholly or in part, by crystalline calcite, somewhat binding unweathered blocks together. This is universally the case with the blue-black slates, and more commonly so with the gray; but such fillings do not occur in the graphitic slates. This would indicate that the calcareous matter was largely derived from the slates themselves, and that the graphitic slates lack it from having contained none originally. Generally these fillings are mere films, but occasionally wider fissures occur which contain calcite masses of considerable size. The large blocks of white crystalline

marble occurring on some of the moraines have had such a source. Two large calcite seams of this character show beautifully on the eastern face of Pyramid peak, looking, to an observer in Dying glacier valley, like rills of water on the mountain side. In the vicinity of the eruptives these fissures are often metalliferous, and occasional quartz veins occur.

Careful search for fossils was made in these argillites at many points, but no discovery rewarded the search. It is very possible that the series comprises rocks of more than one age. The whole is so homogeneous in appearance that its dissection, if dissection is possible, will be a matter of vast and painstaking labor.

The Limestone.—The mountains forming both shores of the larger part of Glacier bay, and all the islands in the bay except the two in Muir inlet and the Beardslee islands, are made up of metamorphic limestone. This first appears on the eastern side of the bay, forming the mountain peak just south of the peak of mount Wright, follows along the mountain summits for some little distance with slight dip and then abruptly plunges down to the shore with a very steep southerly dip. Near its contact with the slates it contains considerable argillaceous admixture; otherwise it is an extremely pure dolomitic limestone, containing only a trace of insoluble matter. More commonly it is of a dark purplish tint, though some portions are drab. It is cut by the same fissure systems as the argillites, but is bound into a more compact mass by the calcite which everywhere completely fills the fissures, so that it disintegrates with less rapidity. Search for fossils in the limestone was rewarded at only one locality, on the island in Glacier bay nearly due south of Headland island. Here but a handful were found. The only recognizable forms were shells of *Leperditia*. Sections of large gasteropods showed beautifully on the highly polished limestone surface, but it was impossible to break out specimens which would give any indication of external form. I sent the collection to Professor H. S. Williams for examination. He replied that *Leperditia* was recognizable, while the others would scarcely repay careful examination; that the age was probably Paleozoic, but that the collection would warrant no more decisive statement. The superior limit of the limestone was not seen, but it has a thickness of several thousand feet. It appears conformable with the argillites below, indicating their probable Paleozoic age.

Eruptive Rocks.

Slides of all the eruptive rocks found in the district, ground by the United States Geological Survey, through the courtesy of the director, were sent to Dr George H. Williams for examination. It is much to be regretted that, owing to a misunderstanding, no field-notes were sent him. His paper accompanies this, and to it the reader is referred for the nature of the rock species under discussion (supplement ii). There are two main classes of igneous rocks in the district: (1) ancient eruptives occurring in large masses, classed as diorites by Dr Williams, and (2) more recent eruptives, occupying dikes generally of small size, which cut both the sedimentary and the older eruptive rocks.

The Diorites.—The northern and northeastern tributaries of Muir glacier have brought down on their moraines great quantities of diorite, derived from the mountains adjoining the upper portions of their valleys. These diorite mountains lie just north of those of argillite which form the southeastern boundary of the glacial amphitheater. I saw the rock in place only from a distance, and had no opportunity to examine the contact between it and the argillite. This renders it impossible to state which of the two is the older. No evidence of shore conditions is observable in the vicinity of the contact, nor is there any evidence perceptible to the eye that the argillites derived any of their material from the diorite, affording a slight negative evidence in favor of the diorite being the younger. To the eye the diorite seems to consist of nearly black hornblende and a white plagioclase, the hornblende largely predominating. A distinctly foliated arrangement is often observable, simulating a rough gneissic structure. In the main it is fine grained, but sometimes quite coarsely crystalline.

Quartz-diorite.—Another great plutonic mass, having a very different appearance from the last and completely separated from it in the region examined, is described as quartz-diorite by Dr Williams. Its outcrop is fan-shaped, running out toward the east, but having a great development toward the northwest and west. Nunataks *G* and *H* are composed of it, and also the mountains toward the west and northwest as far as the eye can reach, the peculiar light tint of the rock making it easily recognizable at some distance. The moraines that come down from that direction are almost entirely composed of this material. To the

eye this rock consists of a mixture of white plagioclase and glassy quartz, in which is imbedded occasional prisms of hornblende which seldom have a length of less than a quarter of an inch; occasional plates of biotite also occur. The contact of this rock with the slates is best shown on the northern wall of the valley of the small glacier which lies north of Pyramid peak and was formerly tributary to Dying glacier. An angle in the wall cuts through the slates into the quartz-diorite, showing two contacts. The westerly one is sharp and nearly vertical. The eastern one is inclined toward the west, and numerous stringers are seen penetrating the slates. This indicates the more recent date of the eruptive rock. The slates in the near vicinity are apparently not greatly affected by the heat consequent on this outflow, but the same holds true of them when in juxtaposition to the more recent dikes, and is accounted for by the metamorphosed condition of the whole series.

Three small exposures of rock, clearly distinguishable from the main quartz-diorite mass macroscopically, but which Dr Williams also describes as quartz-diorite, occur. One of these is on the most northerly spur of mount Wright, at Mr Reid's station *E;* another forms the southern projection of the ridge west of Granite canyon; the third is found cutting the limestone on the shore of the bay 10 miles south of Muir glacier. Their relations to the main mass could not be determined. They are easily distinguishable from the main mass, which is very uniform in appearance, by their greater percentage of hornblende and their metalliferous contents. Their contacts with the adjoining rocks clearly indicate their outflow to be of later date than the deposition of those rocks.

These quartz-diorites are clearly quite old, and have suffered equally with the clastic rocks from the disturbances which the region has undergone. They are cut by the same sets of fissures, though not so numerously; they are also cut by the more recent dikes. Dr Williams strongly urges the ancient date of these diorite masses from his microscopic examination. This is corroborated by their appearance in the field and strengthens the meager fossil evidence obtained as to the early age of the clastic rocks.

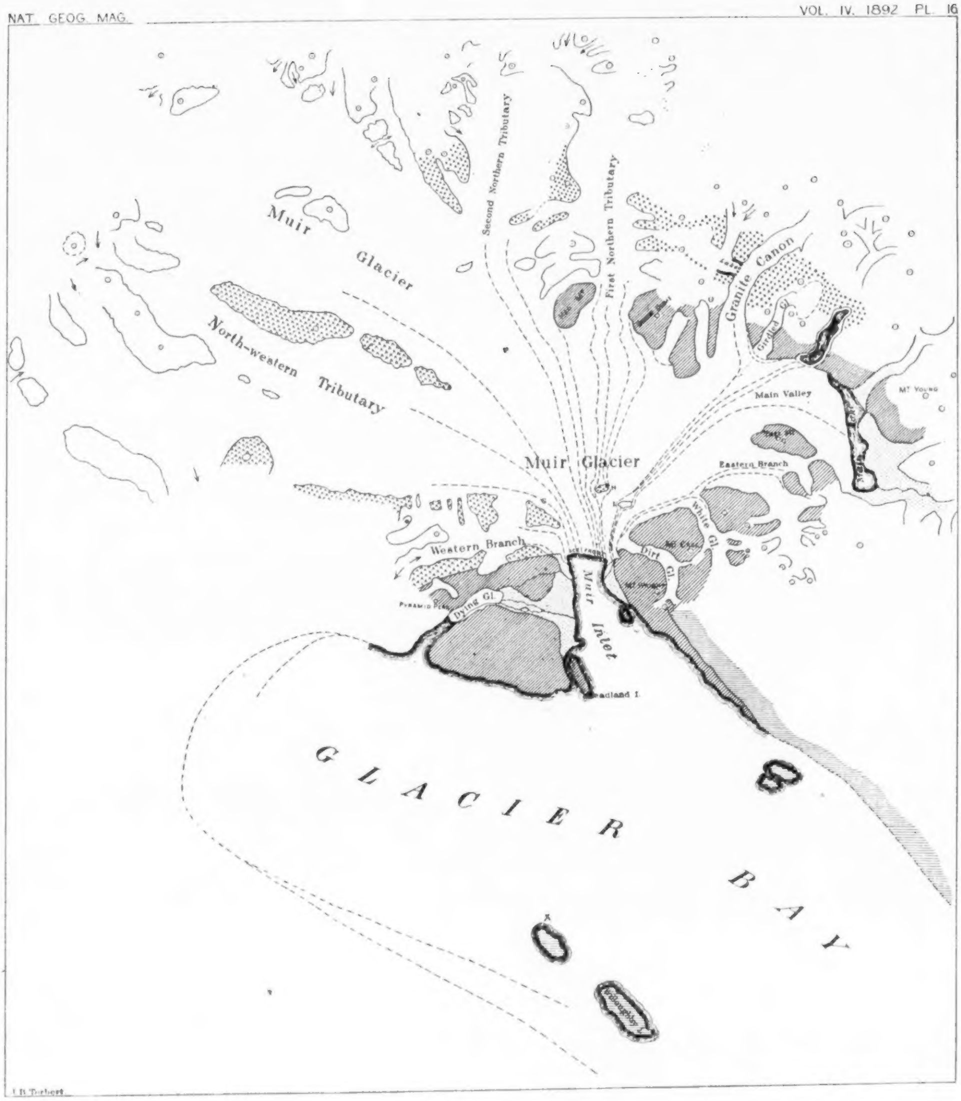
Later Eruptives.—All the rocks previously described are cut by numerous small dikes of later date. The key to their arrangement was not apparent. They seem to lie in all possible atti-

tudes and to dip in several directions, generally at high angles. They seem to follow the fissure systems. Their width is commonly but a few feet, but some were found twenty feet and over. They keep their width with great persistency for considerable distances. No surface flows were found. To the eye all these dike rocks strongly resemble one another. They have a nearly black or dark greenish color, a sandy appearance on weathered surfaces, and are generally distinctly porphyritic in structure, with considerable variation in the size of the porphyritic crystals. The specimens I collected from these small dikes and sent to Dr Williams he classifies without exception as diabases. From a somewhat larger and much decomposed dike on the ridge east of Dirt glacier valley I sent him a specimen which he describes as micropegmatite. What relation this dike bears to the diabase dikes could not be determined, and I found no others like it, though the loose pieces on the moraines show that they occur to the north. With this one exception, all the dikes seen presented a very uniform appearance, save for such slight differences of texture as depend on slight variations in the rate of cooling.

No evidence was found of successive outflows of varying character, though that may be furnished by the exploration of a wider area. The dike rock occurs in blocks of varying shapes and sizes. How much of this is due to fissuring and how much to contraction of cooling I cannot say. That a certain amount of dislocation has occurred since their formation is evinced by the fact that occasionally they are somewhat faulted. But their appearance in the field shows that they have suffered but little dynamically compared with the enclosing rocks.

No direct evidence was forthcoming, bearing on the age of these later eruptives; all that can be stated with certainty being that they are the youngest rocks hereabouts and are contemporary with a great disturbance of the region. Their appearance is very similar to that of certain eruptives of Tertiary age occurring in the Cordilleras further southward. The earlier eruptives indicate a certain amount of disturbance of Paleozoic or Mesozoic date in the region. At a later date further and greater movements took place, the rocks were upturned, faulted, and fissured, and certain of the fissures were penetrated by lavas of Tertiary habit.*

* These later eruptions probably took place at the time of the upheaval of the St. Elias range. See page 24 [H. F. R.].



Diorite · Quartz-diorite · Argillites · Limestone · Glacial gravels · ----Moraines · X Island where fossils were found

Geologic Map

of

Muir Glacier Basin

By H. P. Cushing

SUPPLEMENT II.

NOTES ON SOME ERUPTIVE ROCKS FROM ALASKA.

BY

GEO. H. WILLIAMS, PH. D., OF JOHNS HOPKINS UNIVERSITY.

CONTENTS.

Introduction.

The rocks described in the following notes are for the most part comprised in a collection of fifty erratic bowlders and pebbles gathered near the foot of the Muir glacier by Professor H. F. Reid during his visit there in the summer of 1890. Forty-one of these specimens were examined microscopically, the others being too much altered to repay such a study. Microscopic sections of twelve specimens of eruptive rocks, collected *in situ* near the glacier by Mr H. P. Cushing, who accompanied Professor Reid, were also examined. The description of a single specimen (olivine-gabbro or forellenstein) obtained from the southern side

of mount Cook by Mr I. C. Russell, of the United States Geological Survey, during the same season is also incorporated with the others.

Thanks are due to the director of the United States Geological Survey for his kindness in authorizing the preparation of the microscopic sections necessary for this investigation.

No elaborate or exhaustive study of this material was undertaken: first, because a preliminary examination showed that neither the intrinsic interest of the rocks nor their state of preservation warranted it; and still more because the bare petrographical description of a lot of disconnected hand-specimens, with no information in regard to their occurrence or geologic association, is of but doubtful value.

The real interest of this rock collection consists in the light it throws on the nature of the Alaskan mountains, which are for the present at least inaccessible to the geologist, and in the strong similarity between these specimens and the rocks which have been more carefully studied from portions of the Cordilleras and Great Basin farther southward.*

While none of the specimens in this small series give any clue to the nature or horizon of any sedimentary deposits, we do find in the coarsely crystalline diorites, quartz-diorites and gabbro a correspondence to the most ancient and probably Archean terranes occurring in the regions farther southward which are cut by dike rocks very similar to if not identical with those collected on the Muir glacier by Professor Reid. Although in the absence of geologic data this correspondence is only an indication, still it is too apparent to be overlooked. In the succeeding petrographical descriptions I shall therefore distinguish between the more coarsely crystalline plutonic rocks, whose structure indicates their occurrence in large masses, and the finer-grained though still for the most part holocrystalline rocks derived in all probability from dikes.

These latter rocks, as is usual in such series, cover a wide range, both structurally and mineralogically. The different types pass almost too gradually into one another to allow of any sharp division; and yet for convenience of description, rather than because they stand for any petrographically well-defined groups, they may be ranged under quartz-porphyry

* See J. P. Iddings: Bull. U. S. Geol. Surv., no. 66, 1890, p. 9.

(rhyolite?), hornblende-porphyrite, augite-porphyrite and diabase.*

Coarse-grained Plutonic Rocks.

Not only does the structure of the more coarsely granular rocks examined by me from Alaska indicate that they originated, as above explained, under very different physical conditions from the more finely grained porphyritic specimens, but another of their characteristics renders it probable that they are also much more ancient than these. This is the evidence of extensive dynamic action to which they have been subjected, manifested in the fracturing, optical derangement, granulation, or metamorphism of the constituent minerals. The absence of such phenomena from the dike rocks is the second and more important reason for correllating the coarser specimens with a geologically earlier and possibly Archean terrane.

These plutonic rocks will be considered under the heads of diorite and gabbro.

Diorite.

Nine of the specimens collected by Professor Reid from the foot of the Muir glacier are representative diorites. They are numbered 1, 2, 3, 4, 5, 6, 7, 15 and 22. All are well preserved and differ from one another principally in the coarseness of their grain, in the evidences which they exhibit of dynamic action, and in their proportions of accessory pyroxene or biotite.

Augite-diorite.—Numbers 1 and 2, evidently identical, are rather coarse-grained augite-bearing diorites. Their principal constituent visible to the unaided eye is dark green hornblende, whose cleavage surfaces reach two centimeters in diameter. The spaces

* The terms porphyry and porphyrite must be understood as used throughout this paper in a purely structural sense, with no reference to either geologic age or secondary alteration. In classifying a collection like this one, any reference to geologic age is plainly out of the question, and the specimens, while often much altered, still show the original structure of their groundmass with distinctness. This is in almost every case holocrystalline, and often quite coarsely crystalline, indicating in general a slower rate of cooling than that common to purely surface rocks. In this sense only then are the porphyries and porphyrites herein described supposed to differ from their less crystalline and more superficial equivalents, the rhyolites and andesites. In this usage I profit by the counsel of my friend, Mr J. P. Iddings, whose extensive researches among kindred rocks entitle him to speak with authority upon such a point.

between the hornblende individuals are filled with opaque white feldspar. The hornblende surfaces are often seen to be poikilitic, through a mottling with small idiomorphic feldspar crystals.

Under the microscope the hornblende is brown and pleochroic where freshest. It has the usual tendency to become green or colorless where it has undergone incipient alteration. It is closely associated with a quite abundant pale greenish-gray pyroxene. The two minerals are intimately intergrown, the small areas of the hornblende in the pyroxene looking as though they had resulted from the alteration of the latter mineral. A narrow fringe of hornblende frequently surrounds the pyroxene, while every grain of magnetite occurring in the pyroxene is bordered by a deep green hornblende zone. The feldspar is basic and much striated by twinning. It is also considerably altered to sericite and saussurite.

Augite-mica-diorite.—This rock (number 3) has a much finer grain than the preceding, and differs from it mineralogically in containing a considerable proportion of biotite. As a consequence of this the amount of its pyroxene is much less and occurs only as occasional cores surviving in the center of large hornblende individuals. The hornblende in this rock is full of inclusions which are irregularly distributed, like Judd's "schillerization" products.

Number 4 is a rock quite like the last, but which shows evidence of intense dynamic action. It contains neither mica nor pyroxene in the particular section examined. All the constituents show the effects of pressure. The feldspar especially is bent, broken and dislocated, showing in a beautiful manner a peripheral granulation of the fragments.*

Number 5 is another augite-bearing mica-diorite, which, like the last described specimen, shows the extreme effect of dynamic action. Its feldspars are bent, broken and granulated, while its pale-gray pyroxene is peripherally altered to a new green hornblende, as is the case in the Saxon gabbros and granulites described by J. Lehmann.† Its mica scales are also greatly bent,

* All of the four preceding rocks show a striking resemblance to the diorites described by the writer from the Cortlandt series from near Peekskill, on Hudson river, New York, in Am. Journ. Sci., 3d ser., vol. xxxv, 1888, p. 440.

† Untersuchungen über die Entstehung der altkrystallinischen Schiefergesteine, Bonn, 1884, pp. 193 and 230.

and the interior of its hornblende individuals is often granulated with quartz or albite, as in the Baltimore gabbro-diorites.*

Saussurite-diorite.—Number 6 is a rock similar to those described above, but much altered. Its triclinic feldspar is changed in part to scapolite, in part to saussurite. Its hornblende, of which there is comparatively little present, is largely changed to epidote and its biotite to chlorite. Considerable irregular areas of secondary quartz are also present.

Numbers 7 and 15 are medium-grained diorites with nearly idiomorphic feldspar crystals. They contain much twinned hornblende and accessory biotite. Number 15 differs only from 7 in containing more sphene and apatite.

Number 22 is another diorite much like the last, but whose hornblende has a poikilitic structure, being mottled with plagioclase crystals. This specimen also contains another mineral now wholly decomposed and undeterminable. It somewhat resembles biotite with calcite lenses, but it may once have been cordierite, as it greatly resembles the altered form of that mineral described and figured by the writer in a granite from the Black Forest, in Baden.† The groundmass of this rock consists of nearly idiomorphic plagioclase, much altered.

Number 44 is a diorite which differs from the others in being of a very much finer grain. In the hand-specimen it is dark green and quite aphanitic, while under the microscope it appears as a fine mixture of allotriomorphic green hornblende, plagioclase and sphene. This is evidently a dike rock.

Quartz-diorite.—Closely allied to the foregoing diorites and differing from them chiefly in their content of quartz, are six specimens collected *in situ* by Mr Cushing near the foot of the Muir glacier. These are somewhat more acid rocks than the quartz-free diorites, and are free from pyroxene. They contain either biotite or green hornblende, or both, in varying amounts. Their feldspar is a much striated and almost wholly idiomorphic plagioclase, with a finely developed zonal structure. The quartz, which is not particularly abundant, occupies the interstices between the well-formed feldspar crystals as the augite does in diabase. It is very plainly the last product of crystallization.

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* Bulletin U. S. Geological Survey, no. 28, 1886, pl. iii, fig. 1.

† Neues Jahrbuch für Min., Beil. Bd. ii, 1883, p. 598, taf. 12, fig. 1.

Gabbro of Mount Cook (Troctolite).

In the collection of Alaskan rocks intrusted to me by Professor Reid and Mr Cushing there are no representatives of gabbro, but a single specimen of this type collected in the summer of 1890 by Mr I. C. Russell on the southern side of mount Cook has been sent me by Mr J. S. Diller, of the United States Geological Survey, and may appropriately be noticed in this place.

This rock bears the closest macroscopic resemblance to the well-known forellenstein of Neurode in Silesia,* nor is the likeness less striking when the two rocks are compared under the microscope. The thin sections of the Alaskan rock which I have examined show an evenly granular aggregate of serpentine grains and a basic feldspar, which appears from its optical properties to belong to the labrador-anorthite series. The serpentine now contains no trace of the original olivine from which it has evidently been derived. The feldspar is striped with broad twinning lamellæ, and shows evidence of considerable alteration, although none of the constituents of this rock exhibit any indications of having been subjected to any particular dynamic action. Around each serpentine grain is a border of compact greenish hornblende, which for considerable distances belongs to single individuals.

To designate this peculiar modification of olivine-gabbro from which pyroxene is nearly or quite absent, the English petrographers employ a translation of the German term "forellenstein" (trout-stone) *troctolite.* As early as 1872 Professor Edward S. Dana proposed the name "ossipyte" to designate a rock from New Hampshire of the same mineral composition.†

Fine-grained Dike or Surface Rocks.

A goodly proportion of the specimens examined are fine-grained porphyritic rocks, covering a considerable range of types. Their structure indicates that they belong to small masses, which in all probability break through the crystalline complex of more coarsely granular rocks above described in the form of dikes, or perhaps in some instances cover them as surface flows. These

* Vom Rath: Pogg. Ann., vol. 95, 1855, p. 551; and A. Streng: Neues Jahrbuch für Min., 1864, p. 257.

† Am. Journ. Sci., 3d ser., vol. iii, 1872, p. 49.

rocks, in spite of often possessing an extremely fine-grained groundmass, are in almost every instance holocrystalline. In only rare instances was there a truly amorphous base present in any appreciable amount. For this reason they will be classified for description (in accordance with the foot-note on page 65) as porphyries, porphyrites, and diabases.

Porphyry.

Micropegmatite.—The absence of granitic rocks is noticeable in the series examined from Alaska. The nearest approach to this type appears to be number 13, collected by Professor Reid. Both this and two other specimens which are related to it in the structure of their groundmass, are, however, more basic than we should expect true porphyries to be. They none of them contain any porphyritic quartz. Their phenocrysts are altogether hornblende and feldspar (mostly striated); so that, in the absenceof a complete analysis, they might perhaps be better classified as acid porphyrites.

Number 13 is a pale gray rock of medium grain, which under the microscope is found to be considerably altered. Its porphyritic hornblende is largely changed to epidote and chlorite. Its groundmass is rather coarse in texture, and consists almost entirely of the intimate intergrowth of quartz and feldspar known as micropegmatite. Allied to this specimen is number 7^2 of the suite collected *in situ* by Mr Cushing. This rock has rather an andesitic habit, consisting of porphyritic feldspar crystals or groups of crystals imbedded in a groundmass of smaller, but well-formed idiomorphic feldspars, mostly striated. These are not in actual contact, but are themselves connected by a still finer groundmass of quartz and feldspar, which are united in a very minute micropegmatitic growth. The idiomorphic feldspar forms a very large proportion of this rock. It is considerably altered. The ferro-magnesian constituents, whatever they once were (mica or hornblende), are comparatively rare, and are now almost completely changed to chlorite.

The third specimen, related both in composition and structure to the foregoing, is number 9 of Professor Reid's collection. Its phenocrysts are altogether striated feldspars. Its groundmass is rather fine grained and hypidiomorphic. The micropegmatite here manifests itself in an abundance of pseudospherulitic tufts

and spheres, which grow out from the angles of the porphyritic crystals.

Quartz-porphyry.—The one specimen of the collection which may be classified without doubt as a quartz-porphyry or rhyolite is number 12 of Professor Reid's collection. This consists of a yellowish-white lithoidal groundmass, enclosing sharp crystals of bipyramidal quartz and orthoclase. Under the microscope the groundmass appears to be holocrystalline and obscurely granular. It is full of minute kaolin flakes, due to incipient alteration. The quartz crystals have their forms corroded with characteristic embayments of the groundmass. They are surrounded by a yellow stain. This rock is without doubt acid enough to belong to the rhyolite series, and it has a strong macroscopic resemblance to certain rhyolites; still, in accordance with the principles set forth in the foot-note on page 65, we may more consistently call it a quartz-porphyry on account of the holocrystalline character of its groundmass.

Porphyrite.

Hornblende-porphyrite.—By far the greater proportion of Professor Reid's fine-grained rocks contain amphibole as their only original ferro-magnesian constituent. The amount of this mineral present is usually very scanty, while both it and the feldspars are so altered and decomposed as to be hardly recognizable. Some dozen or more of these specimens, of which thin sections were made for study, are so uniform in structure and composition that they might readily have been derived from a single geologic source, while their weathered condition deprives them of any special interest or individuality.

One of these specimens, however, number 32, is in this respect an exception. It is a brownish-gray rock of typical andesitic habit, which is thickly studded with small white rectangular feldspars. Under the microscope these plagioclase phenocrysts are found to be peripherally and sometimes entirely altered to calcite. The groundmass of this rock is its most interesting feature. This consists of a rather coarse aggregate of idiomorphic or hypidiomorphic feldspar laths and crystalloids of brown hornblende. These are well developed in their prism-zone but are without terminations. They are somewhat altered to chlorite, but on the whole are remarkably well preserved. Magnetite is

also abundant in the groundmass. If, as seems very probable, this rock is really a Tertiary andesite, then it is related to the older camptonite in a way similar to that in which the mica-trachyte of mount Catini, in Italy, described by Rosenbusch,* approaches the minettes.

The remainder of these andesitic rocks must be classified principally with reference to the structure of their groundmass. This is coarsest and most granular in numbers 8 and 17, where it is almost granitic, though with but little free quartz. The former is extensively altered, and the latter, though less so, has its hornblende and part of its feldspar phenocrysts changed to brightly polarizing epidote.

The remaining specimens form a series for the most part holocrystalline, though exhibiting as extreme members a few examples of unindividualized base. Their phenocrysts of plagioclase and hornblende are quite the same throughout. The holocrystalline groundmass, while differing considerably in fineness, is in some granular (19, 25 and 26) and in others microlitic or trachytic (34, 35, 28, 10 and 11). In number 37 a well marked flow structure is apparent in the arrangement of the little feldspar microliths. The uncrystallized character of the groundmass is most apparent in numbers 27 and 39.

Number 38, aside from being a typical andesite like the others, possesses an additional interest on account of containing numerous rounded grains of porphyritic quartz surrounded by absorption halos or zones, like those described by Mr J. S. Diller in basalt † and by Mr J. P. Iddings in basalt and other rocks.‡ This rock once contained an abundance of brown hornblende, which is now mostly altered to green hornblende or chlorite. Its groundmass is hypidiomorphic and granular. The absorption zones, whatever they once were, consist now mostly of green hornblende and calcite.

Augite-porphyrite (*Labradorite-porphyrite?*).—Number 31 is at once noticeable on account of its strong macroscopic resemblance to that well-known type of labrador-porphyrite, the so-called *porfido verde antico*, which is so common among the Roman lapidaries, and which is now known to have been extensively quarried for ornamental purposes by the Romans at Marathonise

* Neues Jahrbuch für Min., 1880, ii, p. 206.

† Am. Journ. Sci., 3d series, vol xxxiii, 1887, p. 45.

‡ Bulletin U. S. Geological Survey, no. 66, 1890.

in southern Greece.* Under the microscope, however, the similarity is seen to be less close. The groundmass of the Alaskan specimen is much finer grained and more altered. It consists of hypidiomorphic laths of plagioclase, magnetite, and secondary calcite. The large pale green crystals of porphyritic feldspar are very much the same in both rocks.

Number 29 is a rock somewhat like that last described, but whose porphyritic crystals are neither so pronounced nor so abundant. Its groundmass is a network of panidiomorphic plagioclase laths connected by a mesostasis which was probably once a glass, but which now is a brown, extremely fine-grained, but brightly polarizing mass carrying chlorite and secondary amphibole. Magnetite is also abundant.

Number 46 is probably also classed as an augite-porphyrite. It is macroscopically a green aphanitic rock in which no porphyritic crystals are visible to the unaided eye. Under the microscope it proves to be a panidiomorphic aggregate of plagioclase and a pale gray pyroxene connected by a green interstitial serpentinous mass, which may represent an original glassy base. The feldspar and pyroxene of this rock are both quite fresh.

Number 36 may be either an augite-porphyrite or an augite-andesite. It is full of zonally banded phenocrysts of plagioclase and occasional glistening black augites. Under the microscope the porphyritic crystals are seen to be largely plagioclase. The pyroxenes have a pale-brown color in the section and are imbedded in an ophitic groundmass of feldspar laths, magnetite, and chlorite. There is some basaltic brown hornblende not infrequently intergrown with the pyroxene.

Diabase.

Quite a number of this suite of Alaskan rocks may with propriety be classed as diabases. These present a variety of structures through which they grade into the augite-porphyrites and andesites. Indeed, in the absence of all knowledge of the field relations, a sharp distinction between these types is impossible.

Number 21 of Professor Reid's collection is a dark close grained rock containing many ovoid white spots. The microscope shows it to possess a rather coarse typical ophitic structure with pale-gray pyroxene, which is surrounded and supplemented by ex-

* See Rosenbusch: Mikr. Phys., 2nd ed., vol. ii, 1886, p. 499.

terior growths of brown basaltic hornblende. These two minerals are always in parallel position—*i. e.*, with their clinopinacoids in common and their extinction directions on the *same* side of their vertical axes, necessitating, as the writer has suggested before, the change of the plane usually designated the unit orthodome, $P\bar{\infty}$ (101), on hornblende to the basal pinacoid, 0P (001), for this mineral.*

The parallel growths of pyroxene and hornblende in this rock closely resemble those described and figured by Rohrbach in the Moravian teschenites.† The rock is in the main quite fresh, but contains considerable patches of serpentinous substance which from their form appear to represent former hypersthene individuals.

Numbers 45 and 47 are medium-grained non-porphyritic diabases whose feldspar forms stout idiomorphic or hypidiomorphic crystals, and whose pyroxene is also to a considerable extent bounded by its own crystal planes. Both are fairly well preserved, although they contain much chlorite, which in number 47 contains highly refractive, spherical bodies. These are isotropic, but their nature could not be determined.

Numbers 20 and 30 are both considerably altered porphyritic diabases, which form transition rocks toward the porphyrites. Their groundmass is an ophitic mass of feldspar and pyroxene, and their phenocrysts mostly, if not altogether, labradorite.

Number 33 is a coarsely amygdaloidal diabase whose vesicles are filled with epidote and calcite.

Among the rocks collected *in situ* near the foot of the Muir glacier by Mr Cushing are five diabases, three of which are distinguished by the presence of brown hornblende. Of these number 5^2 is almost identical with Professor Reid's number 21. Number 9^2 contains large porphyritic crystals of pale pyroxene, which throughout the rock is idiomorphic and seems to have been the earliest product of crystallization. The groundmass is composed of a network of idiomorphic plagioclase laths, connected by interstitial brown hornblende and serpentinized glass-base. This rather unusual sequence of minerals in diabase makes this specimen particularly noteworthy.

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* Am. Jour. Sci., 3rd series, vol. xxxix, 1890, p. 356.

† Ueber die Eruptivgesteine im Gebiete der schlesisch-mährischen Kreideformation: Tsch. Min. u. Petr. Mitth., vol. 7, 1886, pg. 1. taf. i.

The other three of Mr Cushing's diabase specimens are quite typical representatives of this rock, although they are all considerably altered. They differ mostly in the coarseness of their structure. One contains a little basaltic hornblende and one is slightly amygdaloidal.

PETROGRAPHICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY, *April, 1891.*

SUPPLEMENT III.

MICROSCOPICAL EXAMINATION OF WOOD FROM THE BURIED FOREST, MUIR INLET, ALASKA.

BY

FRANCIS H. HERRICK, PH. D.

The wood which I examined at the request of my friend, Mr Reid, is in a remarkably perfect state of preservation. Weathered portions are somewhat decomposed at the surface and show traces of wood-borers, but the deeper parts are perfectly sound. The wood is of medium weight, fine grained or of medium grain, and compact. It is odorless and light brown in color, the grain being noticeably brownish. This color is due principally to a brown, or slightly reddish-brown, homogeneous deposit in the cells of the medullary rays. As no portions of the bark were obtained, I can speak of the structure of the wood only. This is illustrated by two drawings (figures 4 and 5) of thin sections made in longitudinal. vertical (tangential to the medullary rays), and transverse planes respectively.*

Two elements only are met with in the wood, namely, tracheides, or wood-fibers, and the parenchyma of the medullary rays. The tracheides are characterized by the presence of bordered pits on their walls, a common mark of the wood of coniferæ. The outer border of the pit is about $\frac{1}{64}$ mm in diameter, and the inner border or aperture is $\frac{1}{320}$ mm. The aperture of the canal leading from the cavity of the pit to that of the fiber is frequently slit-like (figure 4, *a p*), and in the preparations this slit is all that can be seen, in most cases, when the fibers are viewed *en face*. The outer border of the pit can, however, be distinctly seen in exceptional cases. The pits shown in figures 4 and 5 were introduced from another part of the section. The dotted lines in the adjoining fiber show the probable outlines of the pits in that cell. The two openings of the pit cavity are shown where the slits apparently intersect. The cavity of the pit is

* Before sectioning the wood was soaked for about a month in glycerine.

sectioned in many places between adjoining fibers, as in *p*, figure 4; and in figure 5, *x*, it is seen that neighboring cells communicate with each other by a canal or aperture in the center of each wall of the pit. A limiting lamella sometimes, if not always,

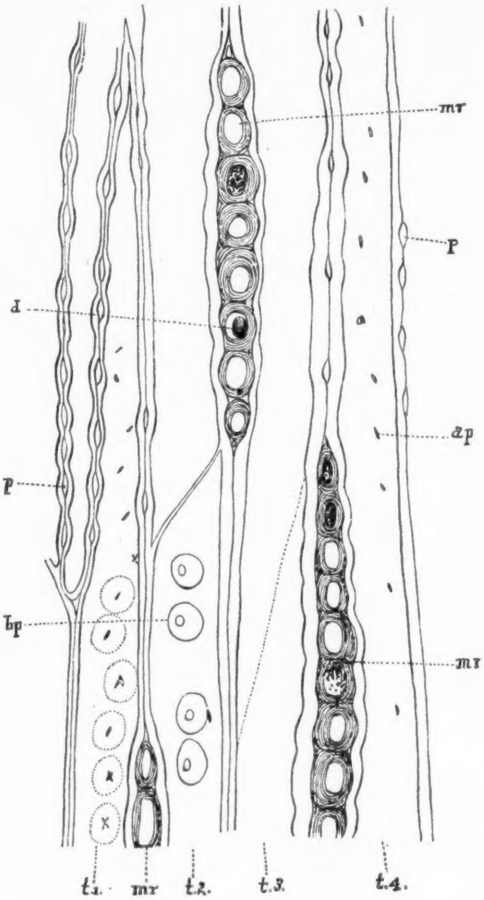

FIGURE 4—*Longitudinal Section of Wood from the buried Forest.*

m r = Medullary ray; *p* = Pit-cavity; *d* = Deposit in cell of medullary ray; *a p* = Aperture of pit; *b p* = Bordered pit; *t 1, t 2, t 3, t 4* = Tracheides.

occurs in the fresh wood of coniferous trees, stretched across the cavity of the pit. This serves as a screen to block the direct

communication of fiber with fiber. No such membrane could be detected in the buried forest specimens.

The medullary rays (*m r*) are very minute, narrow and quite uniformly distributed sheets of parenchymatous tissue. There are about 40 rays to the square millimeter of surface (in tangential section). The rays are uniseriate—that is, one cell broad, as in most coniferæ. The breadth of the ray is thus measured by that of the medullary cell, which is about $\frac{1}{64}$ mm. The height of the rays varies from about $\frac{1}{20}$ to $\frac{2}{5}$ mm, and is from three to about seventeen cells deep. The medullary rays exactly fill the meshes between the bundles of wood-fibers. In some cases the cell-walls of the parenchyma have undergone alteration, and contain the brownish deposit (*d*) already noticed.

The transverse section shows parts of two annual rings or layers (figure 5). In one (the later growth—late summer or autumn,

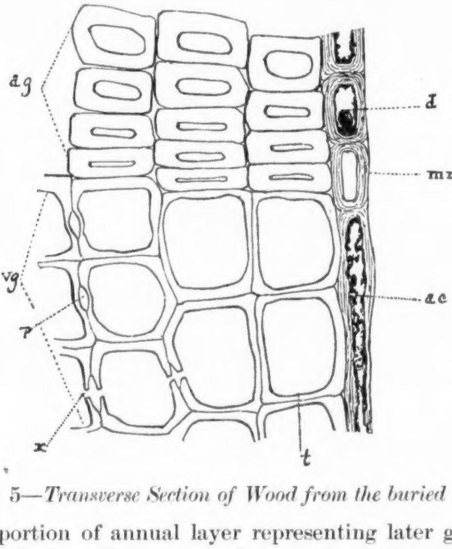

FIGURE 5—*Transverse Section of Wood from the buried Forest.*

a g = Outer portion of annual layer representing later growth; *v g* = Inner portion of succeeding annular layer, representing earlier growth; *d* = Deposit in cell of medullary ray; *m r* = Medullary ray; *a c* = Altered cell wall of parenchymatous tissue; *p* = Pit-cavity; *x* = Internal opening of pit; *t* = Tracheide.

a, g) the cells are flattened and have very thick walls; in the other (the earlier growth—spring or early summer, *v, g*) the cells are much larger, and the walls are thinner. Pits occur in both

late and early wood, although they are represented in the drawing only in the latter.

A specimen of recently grown spruce was obtained by Mr Reid from Alaska,[*] and I have compared it carefully with the preceding and find that the two agree in every structural detail. Figures of transverse and longitudinal sections of the recent wood are not given, since they would be merely repetitions of figures 4 and 5. The size and shape of the medullary rays are essentially the same, and the average number of rays per square millimeter of section is the same in the two specimens. Resin canals are occasionally seen in the midst of a thickened medullary ray in the modern wood, and while I have not observed them in the buried-forest wood, yet I have no doubt that they would be found by persistent sectioning. Transverse sections of the new wood show the same differentiation between the earlier and later cells of the annular ring. The modern wood is several shades lighter than the old, and the brownish tinge of the grain is due to the color of the medullary tissue. The conclusion would be warranted, upon the evidence above given, that the wood taken from a forest at one time buried under glacial deposits in Alaska and submitted to me for examination by Mr Reid is specifically identical with that of the Alaskan spruce (*Abies sitkensis* or *A. menziesii*) which grows in the neighborhood of the glaciers of Alaska to-day, provided that microscopical examination of the wood alone could be relied upon for the determination of species of coniferous trees. Unfortunately for the student of this subject, the structure of the wood must be supplemented by other characters before the species can definitely be settled. The preceding observations can, however, be said to render quite probable, at least, the conclusion intimated above.

ADELBERT COLLEGE, *March 14, 1891.*

[*] This was sent to me from Juneau by Reverend Eugene S. Willard. H. F. R.

APPENDICES.

Appendix I.

LIST OF PLANTS COLLECTED NEAR MUIR GLACIER;

DETERMINED BY

W. W. ROWLEE, BOTANICAL DEPARTMENT, CORNELL UNIVERSITY.

Anemone multifida, DC.
A. narcissiflora, L.
Ranunculus repens, L.
Aquilegia formosa, Fisch.
Aconitum napellus, L., var. *delphinifolium*, Seringe.
Arabis (?)
Arabis ambigua, DC. (?)
A. petræa, Lam.
Cardamine hirsuta, L.
Arenaria lateriflora, L.
Honckenya oblongifolia, Gray.
Cerastium alpinum, L.
Geranium erianthum, DC.
Lupinus versicolor, Lindl.
Astragalus frigidus, Gr., var. *americanus*, Wats.
Oxytropis monticola, Gr.
Hedysarum mackenzii, Rich.
Spiræa pectinata, Gr.
Dryas drummondii, Hook.
Geum calthifolium, Smith.
G. strictum, Ait.
Potentilla anserina, L.
Rubus arcticus, L.
Rubus pedatus, Smith.
Saxifraga davurica, Willd.
S. pseudo-burseriana, Fisch.
S. tricuspidata, Retz.
S. æstivalis, Fisch.
Heuchera glabra, Willd.
Parnassia fimbriata, Banks.
P. palustris, L.
Sedum rhodiola, DC.
Epilobium hornemanni, Reichb.
E. affine, Bongard.
E. latifolium, L. (purple).
E. latifolium, L. (white).
E. angustifolium, L.
Conioselinum fischeri, Wimm. and Grab.
Cornus canadensis, L.
Valeriana sitchensis, Bong.
Solidago multiradiata, Ait.
S. humilis, Pursh., var. *nana*, Gr.
Aster foliaceus, Lindl.
A. peregrinus, Pursh.
Erigeron ursinus, Eaton (?)
Erigeron (?)
Senecio (?)
Antennaria dioica, Gaertn. (only female plant).
Anaphalis margaritacea, Benth. and Hook.
Achillea millefolium, L., var. *lanata*, Koch.
Arnica unalaschensis, Less.
A. latifolia, Bong.
Campanula lasiocarpa, Cham.
C. scheuchzeri, Vill., var. *heterodoxa*, Gr.
Pyrola secunda, L., var. *pumila*, Gr.
Bryanthus glanduliflorus, Gr.
B. aleuticus, Gr.
B. empetriformis, Gr.
Trientalis europaca, L., var. *arctica*, Ledeb.
Romanzoffia sitchensis, Bong.
Veronica alpina, L.
Castilleia parviflora, Bong.
C. coccinea, Spreng.
Euphrasia officinalis, L.
Rhinanthus crista-galli, L.
Pedicularis verticillata, L.
Pinguicula vulgaris, L.
Phlox cæspitosa, Nutt.
Gentiana parryi, Engl.
G. arctophila, Griseb.
G. amarella, L., var. *acuta*, Hook. f.
G. prostrata, Haenke.
Polygonum viviparum, L.
Veratrum viride, Ait.
Salix ovalifolia, Traut.
S. sitchensis, Sauson.
S. reticulata, L.
S. arctica, Pallas.
S. speciosa, Hook. and Arn.
Aspidium lonchitis, Swz.
A. spinulosum, Swz. (?)
A. s., Swz., var. *dilatatum*, Hornemann
Asplenium viride, Huds.
Woodsia hyperborea, R. Br.
Cryptogramme acrostichoides, R. Br.
Cystopteris fragilis, Bernh.
Adiantum pedatum, L.

APPENDIX II.

METEOROLOGICAL OBSERVATIONS.

BY

HARRY FIELDING REID.

A louvred box, open below, was mounted on posts about 6 feet above the ground; it was about 20 feet behind our tents. In it were placed the wet and dry bulb, the maximum and minimum, and the self-recording thermometers. To one of the supporting posts was fastened a long box with a hinged door in which hung a mercurial barometer (lent by the United States Coast and Geodetic Survey). The rain gauge (lent by the United States Signal Service) was placed on the ground about 30 feet in front of the tent. Readings of these instruments (except the maximum, minimum, and self-recording thermometers) were made three times a day, at 7 a. m., 2 p. m. and 9 p. m. These observations, though made by all members of the party, were under the direct charge of Mr Cushing.*

I append some meteorological data which may be interesting: The difference between the mean temperature at Muir inlet and at Juneau (the latter averaged from 8 a. m. and 8 p. m. readings) will be at once noticed. The observations from the latter place were sent me by the Signal Service.

The dial of the self-recording thermometer showed rapid variations of temperature, amounting sometimes to 5° F. in as many minutes. During our stay at the glacier we had three or four strong southerly gales. The thermometer rose 10° or 15° within an hour, held this high temperature during the gale, which usually lasted six or eight hours, and fell even more suddenly to its usual height. Our highest temperatures were recorded during these gales, even when they occurred at night.

The 2 p. m. barometric mean does not show a depression. This, of course, is partly due to the high latitude, but I do not think that is the whole cause. The difference of temperature between the air over the snow-fields and over the neighboring country is greatest in the early afternoon, resulting in a maximum difference of pressure at that time. The flag at our camp blew more strongly toward the south during the warm part of the day than at other times. For several consecutive days in September it hung quietly all night. Thus the proximity of extensive snow-fields holds the barometer up in the afternoon and interferes with the usual minimum. We have, unfortunately, no observations at a near station with which we can compare our own in order to deduce a quantitative value of the glacier's influence on the barometer.

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* A complete record of these observations has been sent to the United States Signal Service.

Temperature and Rainfall Observations.

	Mean temperature.		Maximum temperature.		Minimum temperature.		Rainfall.	
	Camp Muir.	Juneau.	Camp Muir.	Juneau.	Camp Muir.	Juneau.	Camp Muir.	Juneau.
1890.								
July .	45°.2 F.	56°.9 F.	63°.1 F.	74° F.	35°.4 F.	42° F.	3″.06	5″.51
Aug. .	45.1	55.1	63.9	70	37.2	43	4.88	2.21

Barometer Observations at Camp Muir.

	Mean barometer.			Daily barometer.		
	7 a. m.	2 p. m.	9 p. m.	Mean.	Maximum.	Minimum.
July, 1890...	30″.113	30″.078	30″.077	30″.089	30″.335	29″.565
Aug., " ...	30.115	30.128	30.125	30.123	30.418	29.787

Number of days on which 0.01 or more of rain fell:

	Camp Muir.	Juneau.
July	12	16
August	10	11
September...........................	..	26

Mean humidity at Camp Muir: July, 82.2; August, 83.

APPENDIX III.

MAGNETIC OBSERVATIONS.

BY

HARRY FIELDING REID.

The instruments for this work were supplied by the United States Coast and Geodetic Survey. They were a small magnetometer, known as the Bache Fund magnetometer; a dip circle (number 12) of about 12″ diameter; and a mean time chronometer.

The magnetometer was not adapted for determining the magnetic moment of the needle; and as this was not done until some time after my return, the resulting value of the intensity cannot be considered very accurate. The moment of inertia was, however, determined in the field. *H* is given in c-g-s units (*i. e.*, in centimetre-gramme-seconds).

Special tents were erected for the instruments. The magnetometer was 85 yards and the dip circle 65 yards from our tents. During the observations with the former, the latter was about 100 yards distant.

Date.	Declination.*	Approximate daily range.	Dip.	Horizontal intensity.
Aug. 22, 1890	....	....	....	.150
23, "	....	....	75° 49′.8	.150
Sept. 5, "	....	....	75 51 .7	....
8, "	— 30° 27′.8	0° 6′.9	....	....
9, "	— 30 26 .1	8 .4	....	....
10, "	— 30 24 .1	5 .4	....	....
Mean	— 30 26	6 .9	75 50 .8	.150

* The negative sign means that the north end of the needle points to the east of astronomical north.

Appendix IV.

SUGGESTIONS TO FUTURE OBSERVERS.

BY

H. F. REID.

The accessibility and growing fame of Muir glacier make it certain that parties will frequently spend two weeks or a month there in future summers. They will have the opportunity of making observations of considerable interest.

The most important is the rate of recession of the ice-front. Much the easiest way of doing this is by taking photographs and comparing them with others taken earlier from the same points. These photographs should show the mountains behind. The following would be useful: A photograph of the northwestern corner of the ice-front taken from the beach close to camp Muir, the northeastern corner taken from the top of the bluff on the western side of the inlet, just south of the mouth of the glacial stream; the whole front taken from *E*, the front taken from *V*. This latter would show better than the others what change has taken place and can be compared directly with plate 13. *V* can be found without much trouble. It is the highest point in its neighborhood (3,000 feet), and lies N. 65° W., magnetic, from the peak of mount Wright. It is most easily reached by the stream between it and *E* (see map, plate 14).

Compass bearings also will serve to determine the position of the ice-front. They should be taken on the corners and on any well-defined points of the ice-front. These bearings had better be taken from *M* and *L*. *M* can easily be found. It is on the projecting point of the bluff on the east side of the inlet near the edge. *L* is just opposite and bears N. 70° W. astronomical or S. 80° W. magnetic. The distance between them is 8,019 yards. From such observation the position of the ice-front can be immediately platted on the map and the recession measured. Neither of these methods will yield very accurate results.

The map which I have made, though accurate so far as it goes, is far from complete. The upper parts of all the tributaries and much of the region between them is left blank. Any one with the proper training would find it very interesting to map these portions. Starting from the points *E* and *D*, his map could readily be fitted to mine (see page 54). For such work I strongly urge the use of a planetable.

These suggestions are not, of course, intended for scientific explorers; but for persons of some scientific knowledge who may wish to add to the general pleasure of a stay at Muir glacier the special interest of a definite object, viz, to increase our knowledge of the region. I may say that a small piece of work done well, such as the mapping of a single tributary—*e. g.*, Dirt glacier, White glacier, or Granite canyon—is more useful than indefinite observations over a wider range.